The International Politics of Low Carbon Technology Development: Carbon Capture and Storage (CCS) in India

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Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified.

(Rudra Vidhumani Kapila)

Abstract

This thesis explores the international political dynamics of developing low carbon technology. Specifically, Carbon Capture and Storage (CCS) technology as a climate mitigation strategy in a developing country context is examined. CCS is a technological solution that allows for the continued use of fossil fuels without the large amounts of associated CO_2 emissions. This entails capturing the CO_2 emitted from large point sources, such as a coal-fired power station, and transporting the captured emissions to be injected and stored permanently into geological media. Consequently, CCS is a bridging technology that could provide more time for transitioning to a low-carbon economy.

A case study of India is used, which is an emerging industrialising economy, and is also the third-largest coal producer in the world. India faces a dilemma: poverty alleviation and infrastructure development to support its billion plus population requires vast amounts of energy, which is predominantly based on fossil fuels. Therefore, it was envisioned that CCS would be a sustainable option, which could enable industrialisation at the rate required, whilst preventing the exacerbation of the negative effects of climate change. However, during the period of study (2007-2010), CCS was not embraced by India, despite there being a growing impetus to develop, demonstrate and transfer the technology.

India was reluctant to consider CCS as part of a mitigation strategy, and this thesis focuses on the reasons why. An interdisciplinary approach is used, coupling perspectives from science, technology and innovation studies (STS) with concepts from International Relations (IR) scholarship. This sociotechnical conceptual framework is applied to gain a more holistic picture of the failed attempt to transfer CCS technology to India. Key technical challenges and blockages are identified within India's existing energy system, which have restricted CCS technology implementation. In addition, the political challenges associated with the rejection of CCS by the Indian Government are explored. Empirical evidence is on the basis of elite interviews, an expert stakeholder survey and relevant documents. Another case study on the Cambay basin is used to further demonstrate the influence of political factors on CCS implementation, even in an area considered to have suitable technical conditions. The outcomes of this study have implications for policy addressing global challenges, especially by means of international cooperation and technological change.

Lay Summary

This study looks at how low-carbon, or green, energy technologies are developed in rich countries, which could also be applied in poor countries. The main focus is on Carbon Capture and Storage technology, shortened to CCS, which was being developed in rich countries such as the UK, Norway, Australia and USA. This technology involves capturing carbon dioxide gas, which is a polluting gas that contributes to climate change when it is released into the atmosphere. Carbon dioxide is released as a waste product from large industrial processes, such as a power station that burns coal to produce electricity. The captured carbon dioxide gas is then transported, usually by pipelines, to be stored, or injected deep underground, around three kilometres below the surface, so that it does not escape into the atmosphere. Good storage locations for captured carbon dioxide can be found either on land, or offshore, deep below the surface of the seabed. Many of these suitable storage sites are places where oil or natural gas have already been discovered.

Most countries around the world depend on fossil fuels, such as coal, oil and natural gas to produce electricity to power their factories, buildings and homes. Burning fossil fuels can be quite a polluting process, therefore CCS can be useful for cutting down the amount of carbon dioxide produced by industry and energy sectors. CCS could be especially useful for those countries that are less-developed and need a lot of energy to support their population. One such country is India, which uses a lot of coal because it is cheap and easily available. India needs this fuel to develop its industries, such as steel production, and also to produce electricity for powering its cities and villages. Therefore, India and other poor countries need cheap and clean energy to help lift their people out of poverty. At the time of this study, many experts in rich countries thought that this technology might also be useful if applied in India as part of a global effort to combat climate change.

However, this study found that India was not keen to apply CCS technology. And so, this thesis looks at the technical and political reasons why India rejected CCS. This information was gathered from a series of interviews and surveys with very senior decision-makers in India, as well as technical experts in CCS technologies. The results of this study give a good understanding of the realities of the relationships between rich and poor countries. The findings also show how important these international relationships are and how they can influence key decisions, especially about new technologies which can be useful for limiting the effects of climate change. This work is also useful for understanding the complications for transferring a technology from one country to another.

Acknowledgements

This study encapsulates perseverance in the pursuit of a genuinely bad idea, which is essentially the entire reason anything important ever happens in the first place. And so, there are many to thank for their part in this challenging yet rewarding journey. First and foremost, I would like to thank my supervisors: Stuart 'Beardy' Haszeldine, who kept a sense of humour when I had lost mine; Heather Lovell, whose selfless time and care were sometimes all that kept me going. I would also like to acknowledge my mentor Jon Gibbins, for his relentless enthusiasm and encouragement, but mostly for getting me into this mess in the first place. I must also thank Nils Markusson for his excellent advice in the early years of this project, and also for opening my eyes to the social science perspective.

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Dedication

To the ‘Formidable Five’, who often despair, but never cease to care. This is for you:

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List of abbreviations

AEC	Atomic Energy Commission
Bbl	Barrel (of oil)
BERR	(Former) UK Department for Business, Enterprise and Regulatory Reform
BGS	British Geological Survey
CAT	Carbon Abatement Technologies
CCS	Carbon Capture and Storage
CCSA	Carbon Capture & Storage Association
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CER	Certified Emission Reduction
CIL	Coal India Ltd.
COP	Conference Of the Parties
CRD	Centre for Rural Development (India)
CSLF	Carbon Sequestration Leadership Forum
DECC	UK Department of Energy and Climate Change
DEFRA	UK Department for Environment, Food and Rural Affairs
DFID	UK Department For International Development
DSDS	Delhi Sustainable Development Summit
DTI	(Former) UK Department of Trade & Industry
EC	European Commission
ECBM	Enhanced Coal-Bed Methane
EOR	Enhanced Oil Recovery
EU	European Union
EU ETS	European Union's Emission Trading Scheme
EWP	Energy White Paper
FCO	UK Foreign and Commonwealth Office
FDI	Foreign Direct Investment
GAIL	Gas Authority of India Ltd.
GCCSI	Global CCS Institute
GHG	Greenhouse Gas(es)

GIS	Geographical Information System
GoI	Government of India
GSI	Geological Survey of India
GW	Gigawatt (1GW = 1000 MW)
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IEA GHG	International Enegry Agency Greenhouse Gas R&D Programme
IGCC	Integrated gasification combined cycle
IMF	International Monetary Fund
IMO	International Maritime Organisation
IOC	Indian Oil Corporation
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
IR	International Relations
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MEF	Ministry of Environment and Forests
MMV	Monitoring, measurement and verification
MNC	Multi National Corporation
MOP	Meeting Of the Parties
MoP	Ministry of Power
MST	Ministry of Science & Technology
Mt	Megatonne (1Mt = 1 million tonnes)
Mtoe	Megatonnes of oil equivalent
Mtpa	Megatonnes per annum
MW	Megawatt
NAPCC	National Action Plan on Climate Change
NELP	New Exploration Licensing Policy
NGRI	National Geophysical Research Institute
NSG	Nuclear Suppliers Group
NSI	National System of Innovation
NTPC	National Thermal Power Corporation (India)

ONGC	Oil and Natural Gas Corporation
OVL	ONGC Videsh Ltd.
PP	Power Plant
PSC	Production Sharing Contract
R&D	Research and Development
SEB	State Electricity Board
STS	Sociotechnical system
TERI	The Energy and Resources Institute
TIFR	Tata Institute for Fundamental Research
TIS	Technological Innovation System
UKTI	UK Trade & Investment
UMPP	Ultra Mega Power Plant
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
US DOE	US Department of Energy
US EPA	US Environment Protection Agency
WB	World Bank
WRI	World Resources Institute

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Chapter 1: Introduction

The aspiration to investigate the prospects of Carbon Capture and Storage (CCS) technology in India was a timely proposal. A series of events and circumstances preceding the actual period of study significantly influenced how this research was originally framed. This chapter sets the scene for how the research project came to be, and explains the overall rationale behind this thesis. The key research questions and objectives are presented and explained, along with a brief outline of how the thesis is structured.

1.1 Background

This journey started in 2005; at the time I was working at the Environmental Change Institute, University of Oxford. We were host to the G8 Energy Workshop, where I was first introduced to the idea of CCS technology. This technology entails the capturing of carbon dioxide (CO_2) emissions from a point source, such as a fossil-fuel based power station, and then transporting the CO_2 away from the source to a geological storage location, whereby the emissions are kept permanently from entering the atmosphere. 2005 was an exciting year for CCS, particularly in a political context. For example, there was a strong presence of the Department of Trade & Industry (DTI) at the G8 workshop, promoting their work on Carbon Abatement Technologies (CATs), which included CCS. In addition, the UK held the G8 presidency in 2005; CCS had significant political backing from Tony Blair and, this became evident at the Gleneagles summit, where the potential of CCS technology development and transfer was on the agenda (see UK DECC 2005, p. 5). Notably, the Gleneagles summit hosted not only the G8 nations, but also five emerging economies – China, India, Mexico, Brazil and South Africa; delegations from these countries were also present at the Energy Workshop in Oxford.

Furthermore, CCS also became significantly more prominent on the global stage in 2005 via the Intergovernmental Panel on Climate Change (IPCC), an international institution that launched CCS into the international climate change discourse with their special report. The report considered CCS “as an option in the portfolio of mitigation actions for stabilization of atmospheric greenhouse gas [GHG] concentrations” (IPCC

2005, p. 2). In terms of climate mitigation, the target was large point sources of CO_2, such as fossil-fuel based electricity generation, hydrocarbon (i.e. oil and natural gas) production and processing, or, energy intensive industries such as petrochemical, steel and, cement production. The IPCC report described the process as "consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere" (IPCC 2005, p. 2). Therefore, CCS was viewed as a technological solution for tackling climate change, particularly for industrializing countries. By December 2005, CCS had formally entered into international climate negotiations at the Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC), where CCS methodologies were being discussed under the Clean Development Mechanism (CDM) (See Dixon et al. 2009). Shortly after, the IPCC released methodologies and guidelines for GHG inventories in 2006, including a section on CO_2 transport, injection and geological storage (see IPCC 2006; Chapter 5).

Moreover, in the lead up to this study, i.e. 2005-2007, there was tremendous activity within various legal fora in order to accommodate and support CCS related activities. This included the amendment of the international marine treaty the 1972 London Convention and its 1996 Protocol, a global agreement that regulates disposal of wastes and other matter at sea; the Protocol (1996) was amended in November 2006 and the ratification came into force by February 2007, allowing the disposal of CO_2 in offshore geological formations (see Armeni 2011). At the regional level, negotiations were taking place during this period to ratify the North-East Atlantic 1992 OSPAR treaty, which takes precedence over the London Convention and its Protocol. The amendments to the OSPAR treaty, which also permitted the injection of CO_2 streams into sub-soil geological formations offshore, were adopted in June 2007, and later coming into force by 2011 (*Ibid.*). In addition to the OSPAR treaty, during this period the process for delivering a draft European Directive on CCS to the EU Parliament was well underway. During my time at Oxford, my path crossed with key academics, negotiators and lawyers, all who were either contributing to or, directly involved in, the legal processes for incorporating CCS into international marine and European law.

1.1.1 *The rise of 'Chindia'*

In parallel to the growing international momentum behind CCS, 2005 also marked the beginning of significant growth in the gross domestic product (GDP) of certain industrialising countries, chiefly China and India. During the years 2005 through to 2007, India maintained a GDP growth rate of over 9%, generally referred to as the period of 'miracle' growth, and was often compared to China's growth rate in double-digits (see Table 1.1).

Table 1.1: Annual GDP growth rate from 2005 – 2010 for India and China (source: World Bank).

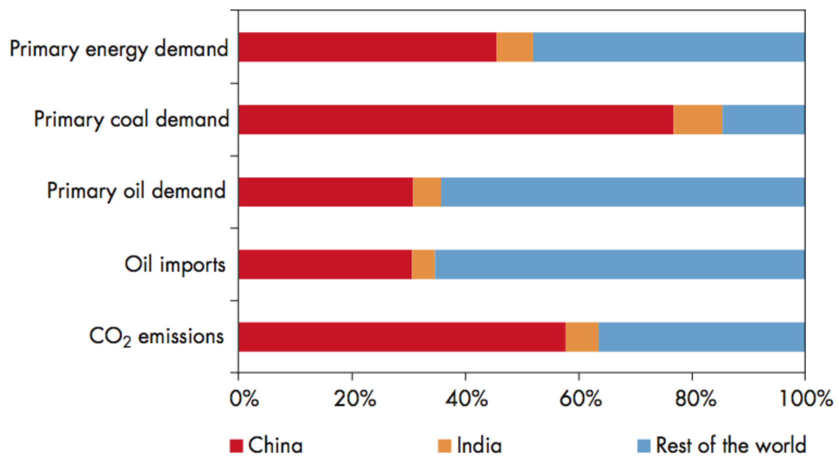
Year	**Annual GDP growth rate (%)**	
	India	***China***
2005	9.3	11.3
2006	9.3	12.7
2007	9.8	14.2
2008	3.9	9.6
2009	8.5	9.2
2010	10.3	10.4

Therefore, 2005 was the beginning of the twinning of China and India by many observers in the West, later to be coined 'Chindia' jokingly by Delhi bureaucrats[1]. The media notwithstanding[2], a major part of the comparisons between the countries was not only to do with economic growth, but also to the inherently linked rise in energy

[1] Credit for coining the phrase and popularisation of this term is given to Jairam Ramesh, former Minister for Environment & Forests, according to Wikipedia (see: http://en.wikipedia.org/wiki/Chindia). However, I personally also heard this term being used repeatedly, from various interviewees during my fieldwork in 2008.

[2] For example, see "Will 'Chindia' rule the world in 2050, or America after all?" *The Telegraph*, Feb 2011. Available at: http://www.telegraph.co.uk/finance/comment/ambroseevans_pritchard/8350548/Will-Chindia-rule-the-world-in-2050-or-America-after-all.html

demand. The International Energy Agency (IEA) published a special version of their annual World Energy Outlook report in 2007 with specific insights on China and India's energy supply and demand portfolios, primarily to assess the implications for global energy security (IEA 2007). Notably, China and India were gaining a reputation as large energy consumers and, both of these countries are heavily reliant on fossil fuels to meet their energy needs. The IEA report highlighted that given the availability of cheap indigenous supplies of coal, it would be the fuel of choice for decades to come (*Ibid.*). In terms of energy demand, it was also noted that "together, the two countries accounted for more than half of the estimated global increase in energy use between 2000 and 2006", where "coal accounted for 43% of this increase in global energy demand" (*Ibid.*, p. 54). This is illustrated in Figure 1.1 below. Also, the IEA's analysis showed that despite indigenous coal resources, the supply would be insufficient to meet increased demand at those rates of GDP% growth in Table 1.1, and therefore, oil imports were also on the rise for these two countries (*Ibid.*; see Figure 1.1).



* Based on preliminary estimates for 2006.

Figure 1.1: Comparison of China and India's energy demand, along with CO2 emissions over the period 2000-2006 (Source: IEA 2007).

Energy security issues aside, the implications for climate change and GHG emissions from this surge in energy demand were a cause for global concern. The CO_2 emissions released by the burning of burning fossil fuels for energy is one of the most significant contributors to climate change (IPCC 2007a; IEA 2007). According to the findings of the IEA's report "58% of the global increase in emissions in the six years to

2006 came from China and 6% from India," illustrated in Figure 1.1 (IEA 2007, p. 55). In addition, the IEA predicted that China would overtake the USA as the world's biggest CO_2 emitter from 2007 onwards (*Ibid.*). However, the report also noted that in terms of energy demand, *per-capita* emissions in China and India would remain roughly one third below member countries of the Organisation for Economic Cooperation and Development (OECD) (*Ibid.*). Therefore, historically and at present, the developed world, i.e. OECD-group of countries, are the primary contributors to climate change; 'Chinidia' were set on the pathway in the mid-2000s to become significant polluters of the future.

It is within this context that it was envisioned that CCS would have a very significant role in climate mitigation. Given that China and India are considered the polluters of the future, this notion of twinning the two nations was supported further by the endorsement of CCS in 2006 by the Stern Review on the economics of climate change, which noted that:

> *"[CCS] is a technology expected to deliver a significant portion of the emission reductions. The forecast growth in emissions from coal, <u>especially in China and India</u>, means CCS technology has particular importance." (Stern 2006, p. 419)*[3]

The Stern report went on further to stress that a "failure to develop viable CCS technology, while traditional fossil fuel generation is deployed across the globe, risks locking-in a high emissions trajectory" (Stern 2006, p. 419). Notably, the drive to develop CCS came predominantly from the West, however it was anticipated that once demonstrated to be viable, it could be deployed in developing countries[4]. This involves the process of technology transfer, which in the context of this study implies the

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[3] Emphasis added.

[4] For the purposes of this thesis, developing countries are broadly defined as those regions that were formerly colonised by Western powers; they have been late to industrialise and sustain very high levels of poverty: Africa, Asia, the Caribbean, the Middle East, and South America (Burnell & Randall 2007). It is also important to distinguish between less developed countries (LDCs), such as parts of sub-Saharan and central Africa, and 'economies in transition', which are chiefly Brazil, China, India, Mexico, and South Africa (IMF 2011).

movement of technology from one country to another. Furthermore, this became evident in not only the strategic interests declared at Gleneagles 2005, but also within various UK Government reports on CCS and discussions within Westminster:

> *"Post-combustion [capture] is the most globally relevant technology. It can be used with existing and planned coal-fired stations globally, and can also be retro-fitted, tackling emissions from power stations that will be in operation for 30-40 years – vital in combating climate change and <u>relevant particularly to China and India."</u> (Memorandum 10, Select Committee on Science & Technology, UK House of Commons 2007)*[5]

Therefore, from the outset there were very strong political and economic drivers behind the development of CCS technology, with the view of 'Chindia' as a potentially significant market. It is these sociotechnical aspects of the proposal to implement CCS in India that the thesis examines.

1.2 Research Objectives, Rationale & Questions

CCS technology and its implementation is the central topic of this research project and, the developing country context chosen as the focus for this thesis is India. As discussed below, India is at high risk from the dangerous impacts of climate change, yet heavily dependent on fossil fuels. The substantial differences between the challenges faced by China and India during the study period also suggest that the twinning of China and India at the time of this study by UK policymakers (see Chapter 4) was an oversimplification. Therefore, in addition to seeking an explanation for India's reluctance to embrace CCS, a part of this research also aims to explore the unique Indian context in depth as a means for highlighting both technical and social challenges. **<u>The overriding objective of this research is to contribute to the wider academic deliberation on the global transition to sustainable energy systems, and in particular, to demonstrate how the integral role of international and domestic politics in processes of technology development can be more robustly represented in theories of sociotechnical systems.</u>**

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[5] Emphasis added.

1.2.1 Evolution of Research Questions

Given the urgency to reduce carbon emissions, and India's ambition to build very large coal-fired power stations, an attempt to identify sites in India that may have potential for early CCS demonstration projects was the original objective of this thesis. Therefore, initial research questions aimed to assess both key technical and policy/legal blockages & barriers within the existing systems in India and, how to overcome them for potential demonstration plants.

However, within the first four months of the study, it became quite apparent that CCS in India was first and foremost a political subject. This was an observation made during preliminary fieldwork, specifically noting the international stance taken by the Indian Government at the DEFRA workshop in 2008, which I attended, along with my principal supervisor. The political dimensions of this topic dominated this first fieldtrip almost entirely. Rather than focusing on the technical challenges involved for the transfer of CCS from a one country to another, the Indian Government made it very clear that they were not interested in implementation or demonstration of the technology in India. It was at this point that this study took a more social and political turn, in response to the findings from this initial fieldwork.

1.2.2 Rationale & Questions

If we regard the Earth's atmosphere as the global commons, then by that respect the increase in GHG gases, which causes climate change, should be an issue of global concern. That being the case, then climate change mitigation requires collective action by countries, both developed and developing. However, how does one reconcile the political differences between state actors? Particularly as the impacts of climate change are not universal and are dependent on unique country contexts, which are influenced by physical and human geographical elements, e.g. natural resources, history, culture, political economy etc. Therefore a comprehensive understanding of country contexts, in addition to the political relationships between state actors is a crucial aspect of the global cooperation required.

Moreover, an important element of the international climate change debate is the development of environmentally sustainable technologies for both mitigation of, and, adaptation to climate change (see IPCC 2007b; IPCC 2007c; de Coninck 2009). Therefore, technological innovation and development have a key role in terms of combating climate change, and the work of de Coninck (2009) illustrates that indeed, technology-oriented international agreements provide greater incentive for countries, and are more likely to encourage effective collective action:

> *"[Such agreements] could provide benefits for all Parties involved. An agreement on technology development, diffusion and transfer would provide for greater innovation and global markets for countries with an outlook on technological leadership." (de Coninck 2009, p. 212)*

The statement above is written in the context of technology *transfer*, because in terms of technological innovation, again, not all countries are on an even footing; developed countries typically have more advanced technological systems, therefore an important factor of climate change mitigation will involve the movement and flow of technology between countries.

Furthermore, there is also the issue that 'technology' cannot be considered in the simplistic terms of its physical components, e.g. pipelines, turbines etc. Other components include social aspects such as institutions, regulations, market, culture etc. In this regard, technology is best viewed as *socio*technical. This perspective allows for an holistic approach and is essential if the technology is to be developed and diffused in multiple country contexts, even more so if it is to be part of an effective process for combating climate change. In this context, the thesis's two overarching research questions, along with subsidiary questions, are as follows:

Q. 1: Why did the attempted transfer of CCS technology to India not occur during the period 2007-2010?

Q. 1(a): What were the specific technical challenges that ultimately prevented CCS technology transfer to India?

Q. 2: Can we better understand this lack of adoption by using a sociotechnical system analysis in conjunction with theories of international relations?

Q. 2(a): How did the UK/developed world framing of the CCS technological system influence the process of attempting to implement CCS in India during the period 2007-10?

Q. 2(b): What are the principal social and political factors that prevented CCS from being considered as a viable climate mitigation option in India?

1.2.3 Research Contribution

This thesis argues that there are three fundamental elements which frame the problem of developing CCS technology for climate mitigation as illustrated in Figure 1.2 (also discussed more expansively in Chapter 2). Firstly, there is the issue of defining CCS technology in *sociotechnical* terms in order to understand its innovation and development. Secondly, if CCS is truly intended to be implemented widely across the globe for climate mitigation purposes, then international dimensions and developing country contexts must be considered. Therefore technology transfer processes, traditionally from developed to developing countries, also become a key factor. Lastly, but just as important, is the third element of the State and its relationship with technology, which in turn also influences its relationship with other states, given that technology transfer processes are involved.

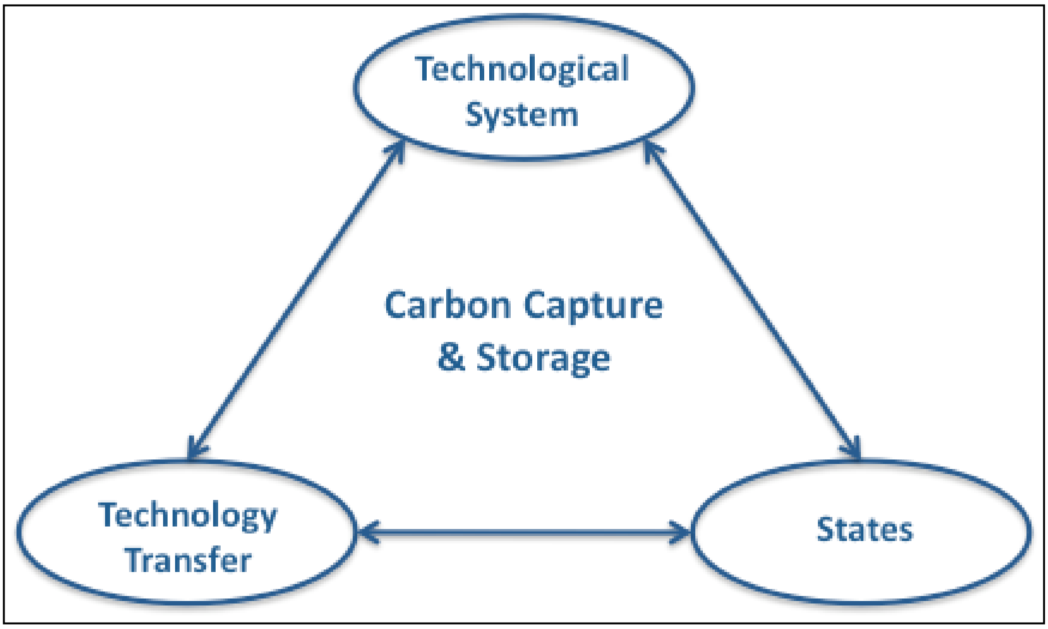

Figure 1.2: Schematic diagram of research rationale, including key elements of technology, technology transfer and states, all which are significant factors for implementing CCS.

In line with the concept shown in Figure 1.2, a sociotechnical approach is applied to the prospect of CCS implementation, in order to understand the challenges. Moreover, where the limits of the sociotechnical approach are reached, this thesis also considers approaches generally more associated with the political sciences. A key contribution of this thesis is, therefore, the combination of insights from political science with a sociotechnical approach to provide a more robust model of the integral role of politics in processes of technology development.

1.3 India's Challenges

Presently, developing countries are faced with a major dilemma: they have to cope with the adverse impacts of climate change and consider whether they should take action to mitigate the risk of more extreme impacts in the future while at the same time reducing poverty. For example, at the start of the study period, statistics from the International Energy Agency (IEA 2007) and the United Nations Development Programme (UNDP 2007/2008) indicated that there were still roughly 2.5 billion people in developing countries who rely heavily on traditional cooking fuels, and around 1.6 billion who have no access to electricity.

India is a developing country that illustrates the nature of this challenge. According to the IEA and United Nations Development Programme (UNDP), it was home to more than a quarter of the world's poor and accounted for roughly 50% of energy impoverished people who have a high dependence on traditional cooking fuels, and for 31% of people without access to electricity (IEA 2007; UNDP 2007/2008). Economic development and the fulfilment of basic human needs such as education, sanitation, health and communication are critically dependent on the availability of modern energy services. For this reason, improved living standards in India are inherently linked with an increase in energy demand. This rise in energy demand has led to an increase in India's overall CO_2 emissions since the vast majority of the increase in energy demand has, so far, been met by increased use of fossil fuels. Over 70% of India's carbon emissions are associated with the burning of fossil fuels, with a significant proportion of these associated with coal-fired power plants. In terms of electricity, India had roughly 138GW of installed capacity, where roughly 70% was generated by thermal power plants, 25% by hydro and 5% from other renewables, mostly wind (IEA 2007).

Alongside these development challenges, developing (and developed) countries focus significant efforts on maintaining 'energy security.' Energy security can be used to refer to a broad range of issues including providing sufficient supply capacity to meet demand, security of reliable access to primary fuel to be used within a country and diversity of supply, which is sometimes seen as a proxy for security of access since it is assumed that multiple supply chains are less likely to fail simultaneously (UNDP 2004). Each definition of energy security brings with it a wide range of factors that must be carefully considered within energy system planning. For example, the United Nations Development Programme (UNDP 2004, p. 42) defines energy security as:

"…The availability of energy at all times in various forms, in sufficient quantities, and at affordable prices, without unacceptable or irreversible impact on the environment. These conditions must prevail over the long term if energy is to contribute to sustainable development. Energy security has both a producer and consumer side."

Nevertheless, the term 'energy security' can have an even more complex meaning in the developing world context. Sethi (2009, p. 20) argues that the increased use of commercial energy by those who currently use more than a 'sufficient' quantity simply because they can afford to do so, threatens the "very existence of those who never used it in the first place, or used it in insufficient quantities and at unreasonable prices." Therefore, in the context of developing countries, such as India, 'energy security' can have strong overtones of equity and can imply a "moral responsibility towards reversing the historic impact on our global commons[6]" (*Ibid.*, p. 21).

The Government of India is committed to the Millennium Development Goals (MDGs)[7], which requires a significant increase in the proportion of the population with reliable access to energy. This will be a significant challenge since India has the world's largest concentration of poor people – over 830 million Indians lived below $2/day, where roughly 370 million of those lived in abject poverty on less than $1/day (UNDP 2007/2008). In terms of energy, over 600 million Indians lived without electricity, and over 700 million still used traditional biomass as the primary fuel for cooking (IEA 2007). The responsibility for providing the energy for cooking through traditional biomass, notably, falls upon women and their daughters, who spend a total of 80 billion hours each year collecting firewood (Gibbs 2008). This dependence on biomass for cooking and heating causes more than 400,000 premature deaths (mostly women and children) in India annually, partly due to poor indoor air quality associated with

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[6] The 'global commons' is anything that no single entity or person controls and that is central to life. It draws on the use of shared 'common' land for grazing animals, where it is likely that everyone will want more than their 'fair share' of the land and the commons are then likely to be damaged for all.

[7] United Nations' Millennium Development Goals represent a global partnership to achieve eight international development goals by 2015, including poverty alleviation, education, gender equality and fighting disease epidemics such as AIDS (UNDP 2005).

traditional use of biomass (IEA 2007). A number of measures are planned including improving and expanding infrastructure for providing electricity.

India's efforts to alleviate poverty are, however, being undermined by vulnerability to climate change. A particular concern for India is that agriculture accounts for around one third of India's Gross National Product (GNP) and directly employs more than 60% of the Indian population (Gibbs 2008). Around 70% of India's population lives in rural areas and recent studies have shown that access to electricity is least among agricultural labourers (Gupta 2009). The Indian Government plans to invest heavily in the rural sectors, seeking to achieve more than 4% agricultural growth according to the draft paper for the 11th national plan, which ran from 2007 to 2012 (Gibbs 2008). The most recent review of the IPCC on likely impacts of dangerous climate change highlighted that India's agriculture and natural resources could be subject to extreme changes, posing a major threat to the livelihoods of millions of people (IPCC 2007b). For example, Himalayan glaciers are amongst the fastest retreating in the world. Glacial meltwater is crucial to Indian agriculture since it feeds the major rivers on the sub-continent and accounts for 37% of India's irrigated land. It is possible that changes in this glacial meltwater will cause water shortages for 500 million people (IPCC 2007b).

A high proportion of India's energy comes from coal. To reduce dependence on coal and increase diversity, Indian policymakers are taking a growing interest in promoting energy efficiency and renewables. Although these measures can be expected to reduce emissions of greenhouse gases compared to use of fossil fuels for energy supply, a key driver for this alternative choice is to try to reduce security of supply concerns related to the country's escalating fuel needs (TERI 2006). The Indian Government also sees a significant role for coal in the future, and is investing in coal-fired Ultra-Mega Power Plants (UMPP)[8]. It was expected that these plants would come online after 2012 (Chikkatur & Sagar 2009).

[8] UMPP has a power generating capacity of 4GW per site.

1.4 Thesis Structure

The thesis comprises of eight chapters in total, including this introductory chapter. Chapter Two discusses key theories from the social sciences related to technology, its development and, transfer. These theoretical concepts largely derive from the field of science and technology studies (STS). However, as discussed within the previous sections of this chapter, quite early on in the research it became apparent that the political dynamics of CCS in India dominated the discourse. Therefore, the relationship between politics and technology is crucial, which in essence adds another dimension to the theoretical framework of this study. Given the international aspects of CCS implementation, there is a critical analysis and discussion of STS concepts in light of international development and technology transfer, along with a review of key concepts from international relations (IR) political theory. Combined, these concepts are used to frame the interdisciplinary approach used throughout this thesis.

Chapter Three presents the methods chosen to gather evidence in relation to the research questions presented above and the theoretical approaches discussed in Chapter Two. Given the nature of the study, the evidence base is almost entirely formed by gathering qualitative data by means of in-depth interviews, participant observation and an expert survey. This is supported by documentary evidence from various government publications and documentation from international bodies, plus peer-reviewed research publications.

The main empirical chapters are Four, Five, Six and Seven. Chapter Four focuses on CCS technology itself; describing the various components that involve capturing CO_2 emissions, transporting them and storing them permanently in geological structures, and when integrated, form the CCS technological chain. This chapter also explores the main drivers for developing this technology and why the UK specifically took the lead during the study period.

Chapter Five explores in detail the Indian context, specifically looking at India's history, the legacy of colonialism, and how the current energy system evolved. This chapter also explores how India innovates, which is a crucial factor to consider in terms of technology receptivity and capability for further R&D on large-scale initiatives such as CCS.

Chapter Six looks at the feasibility of CCS in India, though exclusively within an international context, highlighting the political challenges. This chapter draws upon data gathered during various field trips, including from the UNFCCC COP15 at Copenhagen in 2009, as well as survey material. The focus is on India's international stance on CCS and the reasoning behind it, bringing in elements of international environmental law and India's overall approach to climate change.

Chapter Seven also looks at the feasibility of CCS in India, but the emphasis is on the challenges at the domestic level. The focus in this chapter is on India-specific factors, which will need to be considered first, even if conditions (discussed in Chapter Six) become favourable at the international level. These include sensitive issues such as security and corruption associated with coal-mining areas. A case study of Cambay Basin is included in this chapter to illustrate a context where opportunities for CCS are more promising, but also highlights some of the challenges still remaining.

Chapter Eight is the final chapter, which draws conclusions in light of the research questions discussed above. This chapter also includes a section reflecting upon the overall research process, particularly in terms of the scope of interdisciplinary research, and how to carry this forward for further research.

Chapter 2: Conceptualising Technology and Politics in Relation to Climate Change

2.1 Introduction

This chapter reviews theoretical approaches and concepts from social science literatures relevant to technology, and the various social processes that influence its development. In terms of the development and transfer of CCS in the Indian context, this review draws specifically upon concepts relating to technological change and technology transfer, as well as the political influences on these processes. The overall aim of the review is to identify and discuss the most relevant existing scholarship in order to provide a theoretical framework for this thesis.

All the elements of our present lifestyle are powered by burning fossil fuels. This produces carbon emissions meaning that the development, implementation and use of technology is often viewed as the main contributor to climate change. Yet, it can also form part of the solution by reducing emissions through a combination of low-carbon technologies such as: efficient combustion technologies, storing CO_2 emissions in depleted oil and gas fields, and harnessing clean renewable energy such as solar or wind. Therefore, *technological change*, i.e. either the development or decline of technology, will significantly feature in the global effort to tackle the adverse effects of climate change. However, because our current global energy, transport and food production systems are still entirely dependent on fossil fuel technologies, this will entail undertaking profound structural changes to our infrastructure. Therefore, a suite of technologies, including Carbon Capture and Storage (CCS), could potentially mitigate the effects of climate change by cutting emissions from fossil fuel use, and help us move to a more low-carbon economy.

However, there are peculiar characteristics associated in particular with low-carbon technologies, adding complexity to their development and diffusion. Specifically, Ockwell & Mallet (2012, p. 7) point to three key issues that need to be considered when looking at the transfer of a technology such as CCS to a developing country such as India. Firstly, the potential impacts of dangerous climate change "introduces a temporal concern in the form of urgency", which means that such technologies would need to be developed and diffused quickly in order to allow us to mitigate or adapt. Secondly, given that time is imperative, facilitating low carbon technology transfer requires policies and incentives despite “the absence of an obvious market”, in order to deliver “a global good” (*Ibid.*). Thirdly, many low-carbon technologies have yet to be developed commercially. Therefore, not only is there the task of getting beyond the research and development (R&D) phase by overcoming “high-levels of investor risk”, but also there is a need “to adapt technologies to new contexts” for successful transfer (*Ibid.*). This last point is particularly relevant for CCS technology transfer to developing countries because presently the majority of R&D is carried out in those developed countries with historically fossil fuel based energy systems and the expertise in relevant sectors (e.g. oil and gas exploration, pipeline technology for gas transport or power plant design). Moreover, the current CCS R&D is supported under established institutional and regulatory frameworks specific to those countries, including the UK.

Technological change, its innovation processes, its transfer and its role in social change, is a subject of interest amongst multiple disciplines within the social sciences, including economics, geography, history, psychology and sociology (e.g. Abraham 1998; Castells 2000; Lall & Urata 2003; MacLeod & Kumar 1995; Talalay et al. 1997). The literature on this subject is large and diverse. For the purposes of this thesis, insights are drawn largely from science and technology studies (STS). This is because CCS is currently in the pre-commercial stage meaning the initial innovation and development processes, which form a significant part of the empirical core of STS theories, are important to consider in relation to the empirical material of this thesis. A number of analytical frameworks based on STS concepts have been used to analyse technological change motivated by environmental and sustainability concerns (see van den Bergh et al. 2011). Insights from this field contribute to the understanding of technology that goes beyond the usual science and engineering lens. Outcomes from this particular approach are useful for informing a variety of policies and strategies on issues such as economics, innovation and sustainable development.

Section 2.2 explores some of the STS approaches for understanding and explaining CCS technology and its development; both in terms of innovation theory, as well as transitions theory, which is generally associated with major societal shifts in sectors such as transport, agriculture and energy. In the context of this thesis, CCS is conceived of by some key actors as part of a transition from a carbon intensive energy system to a low-carbon energy system. However, given the three unique aspects of low-carbon technology transfer discussed above, combined with CCS R&D largely taking place in specific developed countries, the developing country context is missing. Therefore, a broader approach is taken by linking STS concepts with insights from international development (Section 2.3) and international relations (IR) theories (Section 2.4). This is because transitions theory largely draws upon a developed country empirical base, generally neglecting phenomena such as *polarisation*[9] in a globally interconnected world, or socio-economic and political differences between the developed and developing world.

2.2 Technology, Innovation and CCS

This section draws upon concepts from a wide body of literature on STS, which centre on innovation and technological change. STS is itself a cross-disciplinary field and includes a diversity of approaches from sociology, economics, human geography and history (e.g. Bijker et al. 1990; Lundvall 1992; Foray & Freeman 1993; Hughes 2004). STS ideas are discussed and used as a means to illustrate the complexities associated with commercially developing CCS, which is shown to have multiple and mixed identities.

2.2.1 Defining Technology

Technology is more than a set of tangible objects, artefacts or tools, which "by themselves have no power; they do nothing" (Geels 2004a, p. 1). Rather, it is "only in association with human agency, social structures and organisations do artefacts fulfil functions" (*Ibid.*), and therefore is a product of "material and socio-cultural configuring" (Rip & Kemp 1998, p. 329). As a result, modern technology consists of a "cluster of elements", including artefacts, user practices, cultural meaning, markets,

[9] O'Bryne & Hensby (2011, p. 2) describe 'polarization' as the "process of increasingly apparent division between two extremes, namely, in this case, a rich world and a poor world."

regulation, infrastructure, maintenance and supply networks (Geels 2004b, p. 19), which are all organized into "a configuration that works" (Rip & Kemp 1998, p. 330). Figure 2.1 illustrates this conceptualization of technology, and this diagram is used further in Chapter Four in the context of CCS technology. This description not only views technology as a social construct, which cannot be separated from society, but is also grounded in a systemic way of thinking, i.e. where a system is composed of units and their interactions, or relationships. This concept highlights the interlinking technical and social aspects of a *sociotechnical system* (Hughes, 1983).

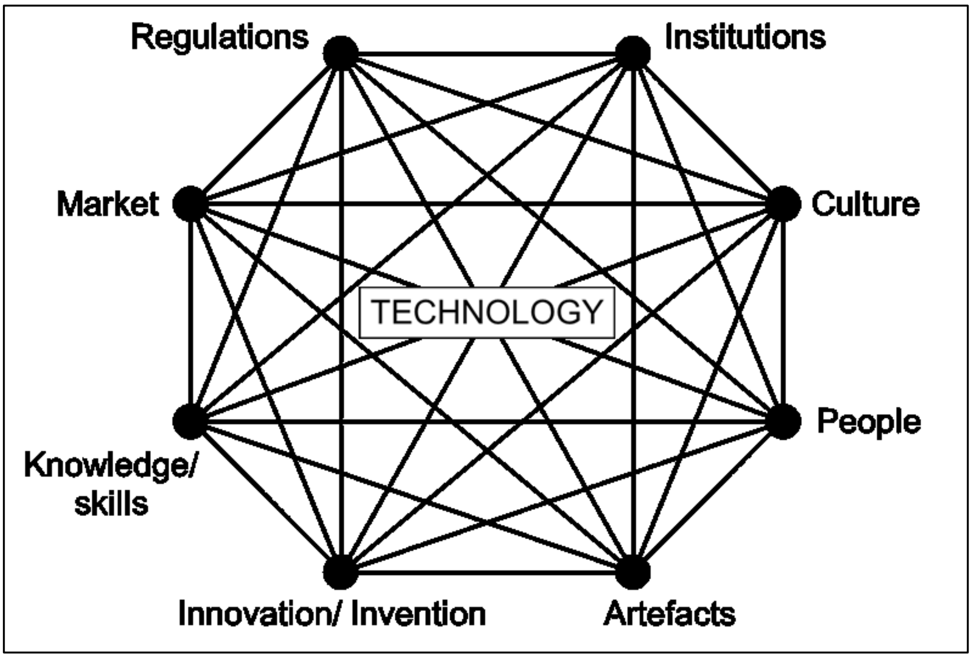

Figure 2.1: Schematic diagram of technology as viewed through a sociotechnical lens.

Consequently, this social constructivist approach regards human relations and societies as being integral to shaping technological systems because not only are people the creators of technology but also collectively, as a society, they influence the development of the technology. For example, the public acceptance (or unacceptance) of nuclear technology forced developers to redesign their systems, particularly for storage of nuclear waste (Mackenzie & Wajcman 1999). And yet, in the same process society is also continually being shaped by advances in technology, such as the various industrial revolutions over time – starting with steam engines on to electricity networks and through to Information Technology and the digital revolution (Hughes 2004). Therefore, technology is "both socially constructed and society shaping" (Hughes 1990, p. 51) and can be viewed as the materialized product of "interconnected political, social, or economic interests, norms, or identities" (Fritsch 2011, p. 32).

Moreover, historical studies on the social construction of technology (SCOT) have shown that different social groups perceive artefacts in different ways, and this in turn influences how the artefact is developed further. This idea of "interpretive flexibility", developed by Pinch & Bijker (1990, p. 40), was empirically-based on the development of bicycles in the nineteenth century, where the design and functionality was influenced by, for example, women and elderly men, who prioritized safety over everything else (*Ibid.* p. 42). The social constructivist approach is therefore useful to consider when analysing low-carbon technology transfer because:

> *"[Such] technologies will be widely adopted not simply because they successfully harness technical principles, but also if their form and function are 'aligned' with dominant social practices, or offer opportunities to realize new practices that are attractive in particular social and geographical settings." (Ockwell & Mallet 2012, p. 10)*

The specific historical and cultural context, as well as the current social norms of developing countries, must be taken into consideration when transferring low-carbon technologies. Accordingly, in its Fourth Assessment Report the Intergovernmental Panel on Climate Change (IPCC) defines technology in the context of climate change mitigation as "the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ('software, know-how for production and use of artefacts)" (IPCC 2007, p. 107).

2.2.2 Defining CCS Technology

CCS technology, as defined within this thesis, comprises of all aspects of the material and design of technology (e.g. turbines, pipelines, drills etc.). Crucially it also includes the skills necessary to install and operate the technology (including infrastructures, division of labour, and cultural norms) and ways of managing the situations in which they can be handled productively. Furthermore, CCS is far more complex than many other low-carbon technologies, and is in essence composed of three different technological systems linked together forming a much larger system. This includes the capture, transport and storage aspects of the CCS chain (see Chapter 4). For example, if low-carbon technologies were to be defined in terms of solely their material artefacts, such as a wind turbines or solar power, then CCS is composed of a suite of technologies that have to be linked together in order to serve its purpose. An illustration of these inter-linking technologies, based on the STS conceptualisation in Figure 2.1, can be found in Chapter Four (Section 4.3, Figure 4.6), which discusses the sociotechnical challenges of defining CCS in more detail.

Even though the capture, transport and storage aspects of the CCS chain contain components that are developed and established technologies in their own right[10], they have yet to be tested at scale. It is only when all aspects of their technological systems (including the social aspects, or 'software' as discussed in Section 2.2.1) are integrated, that they serve the purpose of climate change mitigation. Furthermore, as highlighted in the previous section, the social constructivist approach to technology implies that various social groups can define CCS differently. At this stage, CCS is still open to interpretation by different countries. For example, R&D activities in the US are exploring the possibility of developing CCS technologies in such a way where CO_2 could be used to further hydrocarbon production (USDOE 2012a) or as a chemical feedstock to produce other materials (USDOE 2012b). Accordingly, in the US the technology is referred to as Carbon Capture Utilization and Storage (CCUS). These multiple identities of CCS illustrate the complexities associated with the technology and have influenced its development trajectory. This issue of sociotechnical complexity is discussed in more detail in Chapter Four, which explores CCS technology in more depth.

[10] For example, CO_2 capture in gasification processes; transport of CO_2 for the food and drink industry; CO_2 injection into the subsurface for enhanced hydrocarbon recovery.

2.2.3 Technological Change & Innovation

When a radical invention[11] is successfully developed, and is then commercially deployed, it goes through a process of 'innovation'. Years of research have shown that working, re-working with, existing knowledge, rather than generating new knowledge, is the principal activity in innovation (see Fagerberg et al. 2005). Based on the work of sociologist Joseph Schumpter, innovations can be classified "according to how radical they are compared to current technology" (Fagerberg 2005, p. 7). The literature also distinguishes between the different types of innovation: *radical* innovations involve "the introduction of a totally new type of machinery" that does something in a completely new way; and a "cluster" of such innovations, which combined, can have a far-reaching impact on society, creating "*technological revolutions*" (*Ibid.*). There are also "*incremental*" or "*marginal*" innovations that involve modest changes to make "continuous improvements" to existing technology (*Ibid.*). Lundvall et al. (1992) discuss how the cumulative effect of incremental innovations can have just as high an impact as radical innovations. It is important to consider this differentiation of innovation when it comes to defining CCS technology (see Chapter 4).

Crucial for these innovations are the interactions between organisations and firms, and can be understood as the outcomes of *innovation systems* (see Freeman 1987; Edquist & McKelvey 2000; Fagerberg et al. 2005). Traditionally, innovation studies have been viewed as "the creation, diffusion and use of new ideas applied in the economy" (Lundvall et al. 2003, p. 2). Note, the emphasis is on the *economy*, which is presently at odds with issues such as climate change and sustainable development for industrialising nations such as India.

The innovation systems approach is about exploring the roles of actors and the institutions involved, where Freeman (1987) defines innovation systems as "the network of institutions in the public and private sectors whose activities and interactions initiate, modify and diffuse new technologies." Also, the innovation system

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[11] The Oxford Handbook of Innovation differentiates between 'invention' and 'innovation': "Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice" (Fagerberg 2005, p.4).

consists of "elements and relationships which interact in the production, diffusion and use of new, economically useful knowledge … and are either located within or rooted inside the borders of a nation state" Lundvall (1992, p. 3). This 'national system of innovation' (NSI) approach has been used to determine the relationship between research and economic processes in developed countries, with emphasis on *learning* and interactions between firms and knowledge institutions (e.g. universities, technical institutes and schools) (OECD 1997; Archibugi & Michie 1998).

Consequently, a very large amount of empirical evidence has been generated, which can now be used as a guide to determine what does and does not work in terms of fostering successful innovation for commercial and economic gain (see Lundvall 1992; Foray & Freeman 1993; Archibugi & Michie 1998; OECD 2006). The key insight from these studies is that the 'innovative capacity', defined as the ability to "adopt, adapt, develop, deploy and operate technologies effectively" (Ockwell & Mallet 2012, p. 8) is linked to specific contexts and/or locations, almost exclusively in developed countries. Other than the few notable exceptions, such as the work of Muchie et al. (2003) on African innovation systems, and Edquist & Hommen's (2006) research on small economies in Asia, the empirical base for the NSI approach is predominantly from a developed country context.

Innovation scholars themselves admit that their contribution stems from "a minority of small countries which may be characterized as culturally homogenous and socio-economically coherent systems (Sweden, Denmark and Norway)" (Lundvall 1992, p. 3)[i]. The country context matters because historical events influence a nation-state's technological pathways (e.g. Hughes 1983). As with all nation-states, India has a complex history, and like many developing countries, its colonial past has a huge bearing upon its socio-economic systems, which in turn impacts its innovation and technological systems (MacLeod & Kumar 1995; Abraham 1998; Josephson 2006: 148-196). Moreover, 'national' concepts are becoming increasingly challenged in a world that is characterised by international trade, globalisation and transnational innovation (Lall 1984; Talalay et al. 1997; Fritsch 2011; Ravenhill 2011).

Nevertheless, the NSI method has relevance because certain factors "remain local and national", where the "most important localized factor is specialized competence and learning" (Lundvall 2003, p. 4). This means that different countries have different innovative capabilities, thus impacting the rate at which they acquire technology. In addition, there is a linking between scientific and technical progress with economic growth and international trade. This implies that national governments need to include innovation or research & development (R&D) policy as a key part of their wider economic/welfare policy. This is why the NSI analytical framework features in the development literature, because it also has relevance for developing countries and their acquisition of modern technology, i.e. technology transfer (Archibugi & Lundvall 2002; Muchie et al. 2003). This STS concept is linked with the development literature in Section 2.3, and later, with India's historical energy context in Chapter Five.

2.2.4 The Peculiarity of CCS Innovation

Innovation system concepts do not necessarily have to be restricted within national geographic boundaries; they have also been analysed at the regional level (Doloreux & Parto 2005), the sectoral level (Malerba 2002; Winskel 2002) and at the technology specific level (Jacobsson & Johnson 2000; Bergek et al. 2006). The latter approach, known as the Technological Innovation System (TIS) first developed by Jacobsson & Johnson (2000) has been applied to the development of renewable energy technologies. The TIS framework consists of a set of functions with a focus on entrepreneurial activities and relevant policies to support them, such as knowledge diffusion through networks or the mobilising of resources for knowledge production (Hekkert et al 2007).

This particular approach has also been applied to CCS because the TIS framework transcends geographical and sectoral boundaries, which encapsulates attributes of CCS technology. For example, capture technologies exist mainly within the power sector, and injection of CO_2 requires expertise from the hydrocarbon industry; CO_2 can be captured in one country and transported to be stored in another (e.g. US/Canada collaboration on the Weyburn project, see Table 4.2, Chapter Four). The TIS approach has been used by researchers to explore the roles of actors and institutions within the CCS innovation system in countries that are actively developing CCS technologies, mainly the USA, Canada, Norway, the Netherlands and Australia (van Alphen et al. 2010). Their work highlighted Norway as the country with the most well developed

CCS innovation system; all the countries that were analysed had substantial academic-based knowledge generation and diffusion, though market formation for the technology and entrepreneurial activity were considered to be the weakest aspects (van Alphen et al. 2009; van Alphen et al. 2010).

However, the TIS concept puts a lot of emphasis on 'bottom-up' dynamics and the entrepreneurial aspect that is normally seen in renewable and small-scale single technologies (e.g. Hekkert & Negro 2009). Therefore, it can be argued that TIS might not be the appropriate method to analyse a technology such as CCS, mainly because of its association with existing large-scale technological systems and the need for state-determined development due to the high capital costs; top-down policies may leave very little room for entrepreneurial activity. It is this aspect that separates CCS technology from other low-carbon technologies (e.g. fuel cells, wind turbines, biofuels, electric vehicles etc.).

CCS technologies are linked with mature energy systems, such as centralised power stations, transmission and distribution networks, and fossil fuel exploration and production. These, in essence are technologies that have over time evolved and expanded into very large-scale and complex systems, generally characterised by large firms (e.g. electric utilities and oil companies) and established markets and fiscal policies (e.g. tax regimes and subsidies). Research has shown that such systems are prone to 'system entrapment'. This system inertia, when put in the context of technological systems responsible for 'climate forcing emissions', is referred to as '*carbon lock-in*', a term coined by Gregory C. Unruh (2000). Meaning that in the case of those sectors relating to energy, carbon lock-in is prevalent, therefore making changes to them very difficult (see Walker 2000, Unruh 2000; Unruh & Carillo-Hermosilla 2006). Walker's description of system entrapment can be applied to the current situation of nationalised energy sectors, both in developed and developing countries:

> *"The timely death – and effective adaptation – of technologies (and of technology paths) cannot be taken for granted where large technology systems are involved. It can be ignored least of all where complex products and infrastructures are being constructed over long periods, and where states are heavily involved for whichever reasons. In those contexts, the unfit can attract huge investment and can survive long after they should have been sent to the grave." (Walker 2000, p. 834)*

In addition, Walker also emphasises the role of the champions of the technology, who "can make it their business to reduce diversity", especially when there are scarce resources – "sometimes to the extent of creating technological monocultures, in their efforts to secure the survival of their organisations and their preferred solutions" (*Ibid.*). He argues that developed countries are already locked into a carbon economy, and the diffusion of low-carbon technologies is restricted, despite their obvious environmental or economic advantages, political and economic actors will resist bringing them in (*Ibid.*).

Moreover, in the context of CCS technology transfer to India, Unruh & Carillo-Hermosilla's analysis (2006) on '*globalizing carbon lock-in*' is even more appropriate. Even though the original concept of carbon lock-in is based on "a condition that has arisen through the historic development path followed by industrialized countries", large transition economies such as the BRICS (Brazil, Russia, India, China and South Africa), are, according to Unruh & Carillo-Hermosilla (2006), unlikely to escape carbon lock-in, suggesting that there will be a "transfer of carbon lock-in" (p. 1187). This is partly because these transition economies tend to have development strategies that involve "accelerated construction of key industrial infrastructures" over the coming decades, such as energy and transportation systems. Consequently:

> *"[These] countries are promoting rapid industrialization through the adoption of policies, regulatory frameworks, and development strategies that have proven successful in industrial countries… In this context, fossil fuel-based energy technologies appear to be proven, low relative cost solutions that can respond to the demands of rapid industrialization and quickly provide needed power." (Ibid., p. 1188)*[12]

On that account, it could be argued that CCS technologies will only perpetuate the use of fossil fuels. This not only takes away crucial resources for developing alternatives, but also provides less incentive to choose them, and therefore exacerbates the problem of carbon lock-in (Unruh & Carillo-Hermosilla 2006; Greenpeace 2008; Markusson & Haszeldine 2010). It can also be argued that, given rapid industrialisation based on fossil fuels is the priority, there is a stronger case for CCS technology to mitigate emissions for such countries.

Furthermore, analysis by Shackley & Thompson (2012) indicates that there can be different *degrees* to carbon lock-in, where there are 'high-risk' and 'low-risk' carbon lock-in pathways for developing CCS technologies (p. 104). Their analysis shows that it is possible to eventually escape carbon lock-in, provided that it is 'shallow' or low-carbon risk, which involves constructing new plants that are already fitted for CCS capabilities, or have a mandate that they will be able to use CCS within five to ten years (*Ibid.*, p. 119). For this to occur there needs to be strong market signals as well as political will, both of which are currently absent, even for developed countries that are actively investing in CCS R&D (see GCCSI 2011; UKERC 2012). Even so, both Walker and Unruh agree that the ill-suited technology will always lose, and that lock-in only delays an inevitable technological transition, though "by definition, it is then already too late" (Walker 2000, p. 834).

There are certain issues about CCS innovation in particular that need to be drawn out of the above discussion on lock-in. Firstly, CCS is difficult to define in terms of innovation. Is it just an 'add on' technology to an existing system, or in other words, an incremental innovation? Or is it a radical or revolutionary innovation, whereby its

[12] Emphasis is also in the original quote.

introduction may have a very far reaching impact? For example, if CCS is developed to maintain the status quo in terms of power generation, and deployed to just cut CO_2 emissions, then it can be viewed as an incremental innovation. On the other hand, CCS technologies could potentially promote a shift towards a hydrogen economy, especially if technologies such as Integrated Gasification Combined Cycle (IGCC) are coupled with a CCS system. Shackley & Thompson (2012) point out that there are "radical changes implicit in a shift to hydrogen as a major fuel carrier," and therefore suggest:

> *"CCS could be an element in the technological shift towards low- and zero-carbon technologies through being integral to technological innovation around hydrogen, the supply of which could ultimately come from renewable energy sources." (Ibid., p. 112)*[13]

Notwithstanding, the question remains that at this stage it is unclear what innovation trajectory CCS technology will take, making it difficult to analyse using established STS theories. The potential to be both incremental and/or radical in terms of innovation gives an added duality to CCS, which is another aspect highlighting the multiple identities of CCS.

Second, the body of scholarship on lock-in discussed earlier highlights the blockages to achieving a major shift, or *sociotechnical transition* towards a low carbon energy system. This phenomenon entails major structural and systemic changes in large sectors (e.g. transport, agriculture and energy), and is generally characterised by long-term processes, complexity and multiple actors, whereby the system is transformed completely, forming a new sociotechnical system (see Rip & Kemp 1998; Geels 2002). In relation to this thesis, the development of CCS technology for climate change mitigation can be viewed as a *sustainability transition,* which is based on:

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[13] Emphasis is also in the original quote.

"… an increasing awareness that solving resource scarcity and environmental problems, notably related to fossil energy use and climate change, represents a very tough problem[14]*, the solution to which requires a combination of technical, organizational, economic, institutional, social-cultural and political changes." (van den Bergh et al. 2011, p. 2)*

Sustainability transitions are unique, because unlike historical transitions that were emergent, these are "goal oriented" (Geels 2011, p. 25). In this context, the goal is climate change mitigation, and Geels observes that "private actors have limited incentives to address sustainability transitions, because the goal is related to a collective good," and therefore "public authorities and civil society will be crucial to address public goods and internalise negative externalities, to change economic frame conditions" and support low-carbon innovation (*Ibid.*). Furthermore, these types of transitions are characterised by lock-in mechanisms, not only in terms of technological change, but also in other elements:

"It is […] unlikely that environmental innovations will be able to replace existing systems without changes in economic frame conditions (e.g., taxes, subsidies, regulatory frameworks). These changes will require changes in policies, which entails politics and power struggles, because vested interests will try to resist such changes." (Ibid.)

[14] "So tough, that Tainter (2011) is doubtful regarding the viability of a planned and smooth sustainability transition. Drawing from his research on the collapse of ancient civilizations, he argues that solutions to energy scarcity have tended to create more system complexity and associated indirect energy use. A collapse of our civilization appears more likely to him, in line with what happened to ancient societies (Tainter 1990)" (cited in van den Bergh et al. 2011, p. 2).

Table 2.1: The different analytical levels of the MLP (adapted from Geels 2011).

Level	Description	Attributes
Niches *(micro-level)*	"the locus for radical innovations"(p. 26)	Niche actors: entrepreneurs; start-ups; spin-offs Protected spaces, e.g. R&D laboratories, subsidized demonstration projects
Sociotechnical regime *(meso-level)*	"the locus of established practices and associated rules that stabilize existing systems" (p. 26)	Consists of "set of rules that orient and coordinate the activities" of existing sociotechnical systems (e.g. institutional arrangements & regulations; legally binding contracts; lifestyles & user practices) (p. 27) Characterized by many lock-in mechanisms
Sociotechnical landscape *(macro-level)*	The wider context that influences niche and regime dynamics	Includes: demographical trends; political ideologies; societal values; macro-economic patterns

Therefore, it can be argued that sustainability transitions require a broader approach in terms of analysis. Based on concepts from STS, evolutionary economics and historical transitions theory, Frank W. Geels, developed a broad analytical framework called the multi-level perspective (MLP), which draws upon the work of other STS scholars (e.g. Hughes 1983; Bijker et al. 1990; Rip & Kemp 1998) and "views transitions as non-linear processes that results from the interplay of developments at three analytical levels" (Geels 2011, p. 26). The three levels of the MLP framework (niche, regime & landscape) are summarized in Table 2.1. This approach has been used by Geels to analyse transportation systems, such as the piston engine aircraft to jetliners in American aviation (1930-1975) (Geels 2004a), to more recent low-carbon transitions in the UK and Dutch auto-mobility systems (Geels 2012).

The MLP emphasises the regime level, or the existing systems, "because transitions are defined as shifts from one regime to another regime" (Geels 2011, p. 26), and it goes beyond the TIS approach discussed earlier in this section. Geels (*Ibid.*, p. 25) argues that even though the TIS approach is also multidimensional, it "does not address structural change (how emerging innovations struggle against existing systems)", nor does it address cultural and demand-side aspects sufficiently. Therefore, the MLP can potentially be a more useful method for analysing low-carbon transition technologies.

However, as the discussion in the previous sections has shown us, CCS technologies are difficult to define in terms of innovation and can be best described as "an interloper from within the sociotechnical regime itself" rather than a radical innovation that "comes from the margins – from the niche hinterland of dominant sociotechnical regimes" (Markusson et al. 2012, p. 8). Again, this aspect highlights the mixed identity of CCS, wherein it consists of a combination of new emerging technologies, as well as mature, incumbent technologies. Markusson et al. (2012, p. 8) observe:

> *"[CCS] comes from the same companies that already produce power and chemical plants or components thereof such as Mitsubishi, Doosan, Siemens, Alstom, Flour etc. CCS is promoted, developed and planned for by the incumbents in the electricity generating sector (existing utilities) and from the oil and gas companies that develop and manage hydrocarbon reservoirs." (Ibid.)*

Consequently, CCS can be viewed as a "defensive technology developed by the existing system incumbents," and therefore not quite fitting the MLP framework (*Ibid.*, p. 9). Winskel (2012, p. 214) argues that STS approaches such as the TIS and even the MLP are rooted in the constructivist school of thought, where radical niche technologies are essential for systemic changes for sustainable transitions, and therefore are not suitable frameworks for analysing CCS technological systems:

> *"As a large-scale technology, drawing partly on components developed from other sectors, fostered largely by regime incumbents, and aimed at adapting rather than replacing established systems, CCS evidently cannot qualify as a system innovation under the constructivist blueprint."* (Ibid.)

According to Hughes (1990), theories adopting a social constructivist ideology "have a key to understanding the behaviour of young systems; technical determinists come into their own with the mature ones" (p. 57). This latter statement points towards *technological determinism*, a school of thought initiated by Karl Marx, and refers to the notion that technology is "the driving force of social change" by which it "establishes a particular set of power relations" (Street 1992, p. 30-31). This view implies that mature technological systems, or Large Technological Systems (LTS) specifically, can "become a globally dominating force", leading to a "concern about real or perceived loss of socio-political control over transformative processes set off by technology" (Fritsch 2011, p. 31). The LTS[15] concept was devised by historian Thomas P. Hughes, who describes technological systems as having life cycles with different phases, including "invention, development, innovation, transfer, and growth, competition, and consolidation." He argues that as these systems grow larger and more complex, becoming a LTS they "tend to be more shaping of society and less shaped by it" (Hughes 1990, p. 56-57).

However, the STS concepts introduced so far still do not in the main explicitly acknowledge the political circumstances that influence the adoption of low-carbon technologies (Meadowcroft 2011). Nor do they address how the development of large energy systems in one country can influence the socio-economic, political and technological systems in another. The international dynamic is missing from existing scholarship. Moreover, Bridge et al. (2013) argue that "the low-carbon energy transition is fundamentally a *geographical process* that involves reconfiguring current spatial patterns of economic and social activity" (*Ibid*., p. 331). This analysis highlights

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[15] The LTS concept predates the MLP, and within the field of STS, MLP has become the more popular theory (van den Bergh et al. 2011; Markusson et al. 2012, p. 7; Winskel 2012). Nevertheless, both concepts are subsets of the wider STS scholarship, and there is overlap between them.

how STS analyses, in particular MLP transitions theory, of energy systems tend to disregard spatial processes:

> *"Indeed, it is the temporal concept of 'transition' – rather than a geographical alternative – that is often mobilised for thinking about the changes involved in developing low-carbon energy systems… 'Transition' readily captures change over time for a given geographical unit (e.g. a country or a region) but frequently overlooks changes in the spatial organisation of the energy system and economic activity more widely. These geographical shifts are both internal (within a particular region or country) and <u>external</u> in that they involve relationships between one country/region and others." (Bridge et al. 2013, p. 332)*

This point is crucial for understanding CCS technology transfer processes, particularly if it is to be deployed globally. In the context of India, presently CCS R&D is taking place outside its borders, therefore technology transfer would not only require interaction with those nations that are actively developing CCS, but also domestic infrastructures (both physical and institutional) would need to be established. Accordingly, this thesis examines CCS technology in India both in terms of international and domestic contexts and challenges.

Furthermore, Bridge et al. (2013) contend that even "contemporary work on low-carbon energy transition", such as the MLP framework, pays little attention "to questions of scale and space", focusing more on the temporal aspects, despite using "geographical *metaphors*" (i.e. niche, regime and landscape) (p. 333). According to the MLP framework the landscape "includes spatial structures (e.g. urban layouts), political ideologies, societal values, beliefs, concerns, the media landscape and macro-economic trends", which is "beyond the control of individual actors" (Geels 2012, p. 473). In MLP terms, issues related to international relations and trade are considered as the wider context, and would therefore lie within the landscape level. However, although recognised as having influence over the niche and regime levels, the landscape is still considered to be exogenous to the sociotechnical system. It is viewed as "an external context that actors at the niche and regime levels cannot influence in the short run" (Geels 2011, p. 28).

In the context of international technology transfer, actors within the niche and regime levels from one country could potentially impact sociotechnical system landscapes in other countries via the *movement* of technology. The literature on technology transfer has shown that the landscape of one country can be influenced by different actors from the regime level in another, particularly through international trade and North-South transfer (i.e. the movement of technology from developed to developing states) (e.g. Mountjoy 1966; Balasubramanyam 1973; Brandt 1980; Meier 1984; Lall 1984; Rosenberg & Frischtak 1985; Mehrotra 1990; Talalay et al. 1997; Josephson 2006). This large body of work on technology transfer addresses the more geographical aspects of technological change, the considerations of which are missing from most STS scholarship. It also emphasises the link between different socio-economic systems, political will and technology transfer, plus its impact on the international system, which is arguably in the landscape level, or at the macro-level. These aspects are discussed in more detail in the following sections.

Recently, a more comprehensive and multi-faceted sociotechnical framework was developed by Markusson et al. (2012) in order to assess the viability of CCS technology in the UK. This approach highlighted a range of key CCS related uncertainties, including full CCS system integration, the diversity of CCS pathways (influenced by technological diversity for each of the components of the CCS chain), and significantly, the political uncertainties. This approach may be more appropriate to assess CCS viability because it takes a historical perspective via case studies, taking into consideration how relevant mature technologies developed to begin with, and then applying them to the present day context. For example, in order to highlight the uncertainties associated with the speed of R&D and scaling up for commercial deployment, one of the historical analogues looks at the UK's 'Dash for Gas' between 1987 to 2000, and compares it with the development of flue gas desulphurisation technology in the USA since the 1960s (UKERC 2012, p. 22). This method of using historical analogues factors in aspects of mature technological systems, such as the prominence of government policies. Such policies are more closely linked to CCS rather than micro-scale technologies and has more application for potential CCS policy creation. Such an approach usefully embraces the multi-faceted character of CCS.

2.3 Technology Transfer

The transfer of technology from one country to another is a complex topic that spans over a number of disciplines, amalgamating interests from economists, International Political Economy (IPE) and development scholars. Insights from these fields have traditionally been applied by policymakers and key intergovernmental organisations (IGOs), primarily for the aim of transferring technology from developed countries to developing, also referred to as 'North-South' transfer, as a means to reduce poverty (Brandt 1980). Therefore, there is a large empirical base within development literature of how developing countries have acquired technology in the past, with earlier studies looking at the agricultural sector (e.g. Boyce 1987), as well as work on Multi-National Corporations (MNCs) and the impact of globalization (e.g. Lall 1984, Talalay et al. 1997; Phillips 2011; Thun 2011).

In comparison, the innovation STS studies discussed in the previous section, are predominantly interested in the transfer of technology within organisations, firms, and sectors. However, as discussed in Section 2.2, the empirical base for technology and innovation studies largely draws upon developed country contexts. Nevertheless, the NSI approach highlights that the innovative capacity of any country, regardless of wealth is crucial. Furthermore, Ockwell & Mallet (2012, p. 9) observe that the transfer of low-carbon technologies in particular "can present significant learning and capacity-building opportunities", though "existing innovation capacities are important in facilitating this kind of process and ensuring its contribution to overall productive capacities in developing countries". In order to add a more international dimension to the concepts, the analysis here links STS with a selection of relevant ideas from development scholarship.

2.3.1 Defining Technology Transfer

The development approach to technology transfer essentially relates to the acquisition of technology. This involves the dissemination of technical knowledge, skills and products from the point of creation or invention, out into a broader sphere of use, where it can be developed further into new products, applications, processes and materials (UNIDO 1996). According to the United Nations Industrial Development

Organisation (UNIDO), this process can occur through two different pathways, illustrated in Figure 2.2. Starting from a non-commercial phase to the commercial (vertical transfer), and subsequently from one operational environment to another (horizontal transfer) (Ricken & Malcotsis 2011).

Vertical transfer entails the dissemination of technical knowledge from research settings such as academia and government laboratories to the commercial sector, including the progressive stages of invention, innovation and full-scale commercial development. This can also occur within a single organisation or a nation. *Horizontal transfer* involves the movement of a technology from one operational environment to another; this could be between companies, industrial sectors, and also countries. The key aspect of this type of transfer is that the technology is already commercialised and the purpose is to spread and extend its application into other contexts.

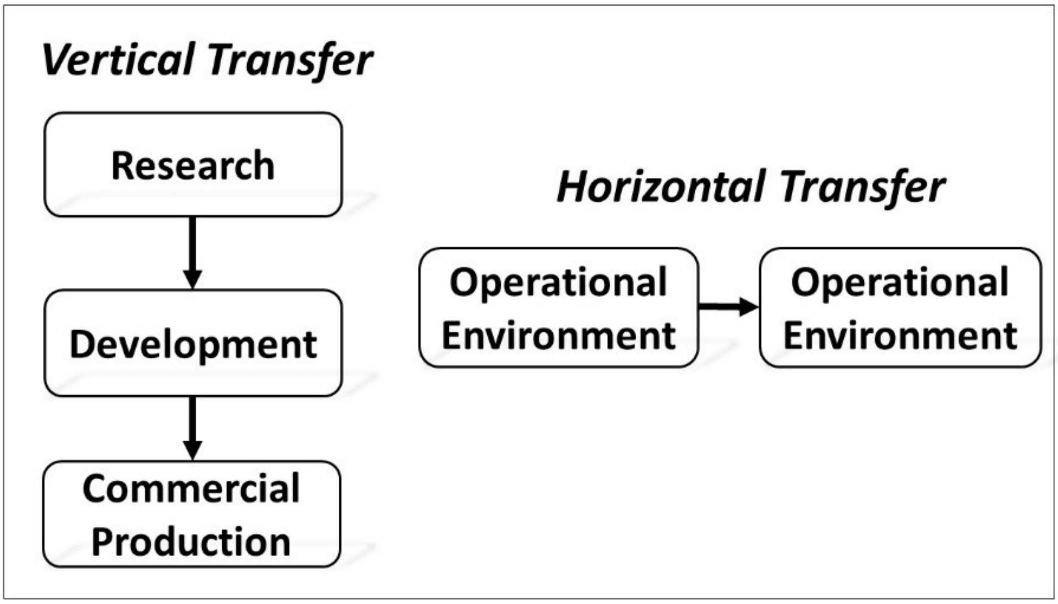

Figure 2.2: Schematic diagram of the types of technology transfer (adapted from UNIDO 2002).

Horizontal transfer has been the traditional means for technology diffusion between developed countries and developing countries (Heeks 1995; UNIDO 2002; UNDP 2005). Notably, Japan is often referred to as a case of an advanced nation that developed in large part through technology transfer, whereas countries such as the UK, US and Germany have relied primarily upon domestically produced technologies. Japan started acquiring technology via horizontal transfer and then created institutions supporting vertical transfer, internalising its innovation with a strong NSI (Freeman 1987). However, it should be noted that the conceptualisation above is linear, and a core contribution of the STS literature reviewed in Section 2.1 is that the process of technological change is *not* linear (e.g. see Figure 2.1). The two bodies of scholarship therefore sit rather uneasily together.

Given that this thesis explores the role of low carbon technology transfer to a developing country in a climate change mitigation context, the special report on *Methodological and Technological Issues in Technology Transfer* by the Intergovernmental Panel on Climate Change (IPCC) provides a useful definition:

> *"… the term "technology transfer" is a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations (NGOs) and research/education institutions… The broad and inclusive term "transfer" encompasses diffusion of technologies and technology cooperation across and within countries. It covers technology transfer processes between developed countries, developing countries and countries with economies in transition, amongst developed countries, amongst developing countries and amongst countries with economies in transition. It comprises the process of learning to understand, utilize and* ***replicate*** *the technology, including the capacity to choose it and adapt it to local conditions and integrate it with indigenous technologies."(IPCC 2000, p. 3)*

The above definition is fairly broad ranging, therefore including the movement of technological knowledge both within nations (horizontal) and between nations (vertical). A key part of the definition for this thesis is the term 'replicate', which, according to the report, refers to the final part of a five-stage process of technology transfer. This includes "assessment, agreement, implementation, evaluation and adjustment, and replication", where the combination of these actions leads to the transfer or "to the deployment of a given technology […] to meet a new demand elsewhere" (*Ibid.*). However, as highlighted in the introduction, low-carbon technology transfer can be challenging because some technologies are not commercially ready to be deployed and transferred, i.e. in the 'replicate' stage. This implies that development policy for low-carbon technology transfer is:

> *"…not simply concerned with their 'horizontal' transfer from one country context to another, but also their 'vertical' transfer from early research and development (R&D) stages through demonstration, early pre-commercial deployment, to commercially viable stages of development." (Ockwell & Mallett 2012, p. 7)*

This describes the present status of CCS, where the technology is still in the R&D stage in specific developed countries, and has yet to be demonstrated ('implementation'), let alone deployed commercially ('replication'). Although, an attempt was made to present CCS technology as more advanced (see Section 4.3.1). The following section explores CCS technology in technology transfer terms.

2.3.2 Technology Transfer of CCS

Analysis later in Section 2.2 develops the idea that CCS has multiple identities with potentially different possible development pathways (e.g. used for Enhanced Oil Recovery (EOR) or for hydrogen production), and therefore would require a particular method of transfer, compared to other more discrete low-carbon technologies such as solar panels, or efficient cook stoves. Presently, CCS is going through both a vertical as well as a horizontal transfer process. For example, in terms of vertical transfer, CCS is currently in the process of being developed from the R&D phase to commercial viability within nation states in the developed regions, chiefly, Europe, North America and Australia (see Chapter 4 and Table 4.2). Specifically, this is still the early stages of the technology transfer where research and academia plays a central role (e.g. van Alphen et al. 2009; van Alphen et al. 2010), and its development is also encouraged by legal reforms, such as the amendments made to the London Protocol and the formation of the EU's CCS directive (GCCSI 2011).

Furthermore, there are crucial associated technological processes that are also being transferred horizontally, i.e. between two different operational environments. This is because there are a number of technologies within the CCS chain that are mature and already at the 'replication' stage, which also reflects mixed-identity nature of the technology. Firstly, there is horizontal transfer between industrial sectors. For example, amine-based capture technology from the gas processing industry, CO_2 transportation from the LPG/LNG shipping industry, and CO_2 injection and monitoring technology from the hydrocarbon industry (see Chapter 4). Furthermore, when these technologies are transferred for CCS applications, it will be because of a change in philosophy, and social and institutional structures will have to be adapted accordingly, e.g. when the focus shifts from *extraction* of fluids out of rock strata, to *containment* within the geological structures (Haszeldine 2011, p. 9)[16].

Secondly, there could potentially be horizontal transfer between countries (and MNCs), such as the proposed Grangemouth project in Scotland, which is essentially a joint venture between the US-based Summit Power Group and the UK's National Grid Plc (see Scottish Government 2012; Summit Power 2012). Subsequently, the result of these initial horizontal transfers could possibly be followed by the development of more novel techniques, which would potentially lead to the next generation of CCS technologies. And so, CCS technology transfer is a complex interplay of vertical and horizontal transfers, and this combination has an impact on how the technology is viewed by developing countries.

Overall, in terms of the definition by IPCC, CCS technology as an integrated system has yet to get to the final stage of technology transfer (replication), and this is likely to take some time. The multiple identities of CCS, combined with lock-in and entrapment issues associated with transitions of large energy systems, which were illustrated using STS concepts in the previous section, are delaying the development of CCS, as explored in the case of India in Chapter Five. This adds to the challenge to develop CCS in accordance with the sense of urgency due to climate change, which forms that basis of frameworks such as set out by the IPCC. Therefore it is difficult to fit CCS within the development frameworks of technology transfer, which are either oversimplified (UNIDO 1996; UNIDO 2002) or were originally designed to suit smaller scale technologies (IPCC 2000; UNDP 2005; IPCC 2007). Nevertheless, the IPCC framework is

[16] Emphasis added.

useful because it emphasises the importance of different *socio*technical environments in different countries:

> *"There is … no simple definition of a "sustainable development agenda" for developing countries. Sustainable development is a context driven concept and each society may define it differently… Technologies that may be suitable in each of such contexts may differ considerably. This makes it important to ensure that transferred technologies meet local needs and priorities, thus increasing the likelihood that they will be successful, and that there is an appropriate enabling environment for promoting environmentally sound technologies (ESTs)." (IPCC 2000, p. 3)*

This links in with the social constructivist approach to technology discussed earlier, implying that different countries can interpret and define technology according to their needs. Furthermore, based on the concept of NSI, which links scientific and technological innovation with wealth creation, development organisations are adjusting their frameworks to put more emphasis on knowledge and learning networks to increase innovative capacity (UNDP 2005; Dutz 2007). The different ways in which discrete technology has been traditionally transferred to developing countries is discussed in the next section.

2.3.3 Evolution of Technology Transfer to Developing Countries

Historically, the movement of technology from industrialised nations to less developed countries is intricately linked to the idea of 'national development', which stemmed from post-Second World War reconstruction (see Meier 1984; Burnell & Randall 2007; Weiss & Daws 2007). In this context, the initial goals of national development were to 'improve national capabilities through industrialisation and overall self-sufficiency', and with the ambition to achieve 'net increases in national wealth and by extension, national power' (Abraham 1998, p. 12). And so, early forms of international technology transfer involved strategies of 'import-substituting industrialisation'[17], which was very popular with newly independent nations, or the

[17] This concept is derived from Keynesian fiscal policy, which advocates a significant role of the government and public sector in order to increase economic activity; based on the macroeconomic

non-aligned 'Third World'[18]. However, even though this strategy was meant to encourage domestic production and commercialisation, the focus was put more on horizontal rather than vertical transfer. As a result, the invention and innovation aspect were by-passed almost entirely, and therefore the development literature puts more focus on the different mechanisms that facilitate horizontal transfer (e.g. Hieronymi 1987; Cooper 1995; Lall 2003). This era also marks the establishment of key international organisations, notably the Bretton Woods Institutions (i.e. International Monetary Fund and the World Bank), which even today, play a central role in financing and facilitating international technology transfer (Woods 2007).

Table 2.2: The different types of technology transfer processes between countries (source material from Thorne (2008) & UNIDO (2002).

	Type of Technology Transfer			
	Material	*Design*	*Capacity*	*Material, Design & Capacity*
Technology Transfer Practices	• Turnkey projects • FDI (in wholly owned or subsidiary company) • In-house transfers to foreign subsidiaries • Sale of products (with or without maintenance) • Counter trade agreement	• License agreements with technical assistance • Transfer of patent rights • Exchange of engineering documents & technical data • Commercial literature	• Training • Commercial visits • Trade exhibits • Tertiary education abroad (with or without on-the-job training) • Site visits • Published trade & scientific literature • Meetings, seminars etc.	• Joint Ventures • Project proposals • International co-operative research efforts

philosophy of 20th century economist John Maynard Keynes, who also helped to set up the Bretton Wood Institutes (see Woods 2007).

[18] 'Third World' countries were part of a non-alignment movement during the cold war, which was spearheaded by leaders from India, Yugoslavia, Egypt, Ghana, Ethiopia and Indonesia. These nations were predominantly poor, and did not want to align themselves with either the Soviet Union (i.e. communism) or the US/NATO (i.e. capitalism) (see Burnell & Randall 2007).

The literature on international business distinguishes between three types of transfer between countries: *material transfer*, *design transfer* and *capacity transfer*. Material transfer refers to physical artefacts, including materials, machines and their parts, as well as turnkey projects[19] and fully operational plants. Design transfer entails blueprints, formulas, handbooks and any other type of information used to build products or production facilities. Capacity transfer comprises of scientific knowledge, education and training not only to operate existing plants but also to enhance technical capacity and capability in order to develop innovations in products and processes (Simon 1991). The different transfer practices currently used by developing countries to acquire technology are listed in Table 2.2.

Traditionally, technology transfer to developing countries has primarily been through material transfer, particularly in the agricultural sector and in the form of turnkey projects. Here, multinational corporations (MNCs) have played a very central role through a combination of Foreign Direct Investment (FDI)[20], license agreements and international joint ventures (Lall 1984; Boyce 1987; Lall & Urata 2003). Over time, since the 1940s, technology transfer now mostly occurs as a combination of the different mechanisms listed in Table 2.2. This has helped newly industrialised countries, such as Taiwan, Singapore, South Korea and Hong Kong, as well as economies in transition, including Brazil, China, India and South Africa, which have also emerged as significant beneficiaries of transferred technologies (IMF 2011).

One of the main concerns regarding technology transfer has been the tendency to treat technology as a 'black box' entity where, due to lack of transparency, the inner workings of a technology are unknown to the recipient country, and therefore prevents

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[19] A turnkey project is an established approach to carrying out international business; usually involves the 'setting up of an industrial plant abroad where the seller enters into a contract to provide the equipment as well as part or all of the services involved in design, detailed engineering, procurement, civil construction, equipment installation, commissioning and training of the local labour force' (Lall 1984, p. 536).

[20] FDI is the purchase by the investors or corporations of one country to another to build a factory, purchase a business or buy real estate (Lall 2004). It can also involve a company from one country making a physical investment into building a factory in another country (e.g. Apple goods made in China).

any innovative activity. This aspect of technology transfer can lead to 'institutional and organisational fragmentation' in developing countries (Malairaja & Zawdie 2004, p. 236), which does not boost local knowledge systems, nor does it foster innovation in the long-term. Particularly, experience with turnkey projects has shown to be unsuccessful, primarily because many of the spare parts or services have to be imported, and the capacity to maintain the technology is not transferred (e.g. Lall 1984; Boyce 1987; Hieronymi 1987). In addition, FDIs and some joint ventures have also been criticised for not building capacity, again due to having a 'black-box' mentality when it comes to technology development (e.g. Heeks 1995; Lall 2003; Thorne 2008).

In principle, joint ventures should offer the best mechanism for effective technology transfer to developing countries because of the potential for learning arising from the interactions between expatriates and local counterparts. However, studies have shown that joint ventures are only effective as promoters of innovation when implemented in countries with higher levels of economic development, and where the industrial culture is well established and the institutional mechanisms for learning from the technologies are in place (Malairaja & Zawdie 2004; UNDP 2005; Dutz 2007; Franco et al. 2011). A study looking at how MNCs operate in Brazil and India found that the host nations' industrial policy was critical in shaping how MNCs 'capture, manage and create strategic assets for innovation' (Franco et al. 2011, p. 1258). Researchers found that, despite the fact that both countries had similar processes for industrialisation (e.g. based on import substitution and development of production capacity), the local knowledge-based assets created by domestic investments and specialisation differed significantly (Franco et al. 2011). This has highlighted the case for a more concentrated education effort to build country-specific innovative capacity, and there is growing concern about the significance of NSIs for technological progress, sustainable industrialisation and economic growth in developing countries (UNDP 2005). Therefore, knowledge and skills transfer are becoming more and more emphasised by the international development organisations of the UN and the World Bank (see UNIDO 2002; UNDP 2005; Dutz 2007).

In other instances, technologies have been transferred without much thought to local social and environmental conditions, and the appropriateness of the technology for the recipient country has been questioned. International development organisations such as the World Bank are considered responsible for many such projects, particularly in the case of coal power plants and hydroelectric dams constructed in the 1970s and 80s in Asia (e.g. D'Souza 2002; Marston 2011). The legacies of such projects are now the source of political instability and security concerns in the region (see Ebinger 2011; Chellaney 2012). These issues are discussed further in the following section.

Apart from the mechanisms listed in Table 2.2, there are other ways that a country may acquire technology, without necessarily involving the typical transaction or long-term collaboration between two parties (i.e. the supplier and the acquirer), which is normally associated with technology transfer. This can occur either through publicly available information, which is becoming easier to access with advancing capabilities in IT, or in some cases it has been acquired through so-called 'reverse engineering'. Both of these routes for technological acquisition require a certain level of capability, which is seen more in the economies in transition, notably China (Ricken & Malcotsis 2011).

Publicly available information can be a source of technical knowledge, however it is unlikely to be commercially operational without an already high level of innovative and adaptive capability within the acquirer (UNIDO 2002). In reverse engineering the artefact, product or system (e.g. mechanical device, chemicals, software programme etc.) is taken apart in order to understand how it functions and 'obtain missing knowledge, ideas and design philosophy when such information is unavailable' (Eilam & Chikofsky 2005, p. 3). Sometimes it can be seen as means to further innovate the technology, or as means to duplicate it, which then raises the issue of protecting intellectual property rights (IPR). The issue of IPR can become a politically contentious subject and is thought to be a key barrier to low-carbon technology transfer (Ockwell & Mallet 2012). Challenges to CCS technology transfer in terms of IPR are discussed further in the empirical chapters.

A key aspect of the IPCC framework for technology transfer that complements STS theories, is the recognition that there are a very large number of actors involved in the processes:

> *"Key stakeholders include developers; owners; suppliers, buyers, recipients and users of technology (such as private firms, state enterprises, and individual consumers); financiers and donors; governments; international institutions; NGOs and community groups. Some technology is transferred directly between government agencies or wholly within vertically integrated firms, but increasingly technology flows depend also on the coordination of multiple organizations such as networks of information service providers, business consultants and financial firms." (IPCC 2000, p. 4)*

However, the IPCC framework also accommodates the fact that many sectors and systems are now integrated internationally due to globalisation. This is important because economic activities between countries, such as trade, investment, and regulation, which are all linked with technology transfer, will create new "spatial configurations and relationships" (Bridge et al. 2013, p. 332). In this way the technology transfer literature adds geography and spatial qualities to its frameworks, which tends to be missing from the empirical base of STS concepts such as the MLP (Bridge et al. 2013).

2.3.4 CCS Technology Transfer & Developing Countries

The International Energy Agency developed a CCS technology roadmap (2010), which indicated that without CCS, the overall costs to halve global emissions by 2050 increases by 70%. And so, at the end of the period considered in this study, it was still envisioned that, CCS technology would play a crucial part in a long-term strategy to cut down carbon emissions globally, and also that the technology should be commercially viable by 2020 (IEA 2010). The objective of this roadmap was also to identify areas worldwide for potential transfer of CCS technology (*Ibid.*). When it comes to CCS technology transfer to developing countries, the process is more likely to be initiated through horizontal transfer, but then will have to be adapted for local conditions via a vertical process. The only current example is Algeria's In Salah project, which is a joint venture between BP, StatoilHydro and Sonatrach (the national oil and gas company of Algeria). Since 2004, 3Mt of CO_2 have been captured from a natural gas processing facility and injected into an onshore deep saline formation (see Table 4.2, Chapter 4). According to the project website, findings of their extensive CO_2 monitoring and verification programme have been shared with stakeholders such as researchers, NGOs, regulators and policy makers (In Salah 2010). They also submitted a new methodology and draft project design to the CDM Executive Board in 2009 as a proposal for including CCS under the CDM.

This form of collaboration includes both dimensions of technology transfer, where established technology is being adapted and tested in a new environment, but there is also emphasis on knowledge and skills sharing which is important for building long-term capacity. Furthermore, building upon those experiences in Algeria, the project aims to highlight the technical and legal issues, which subsequently may be enabling factors for future CCS projects in other developing countries. When taking into consideration the site-specific conditions for potential CCS application, such as available fuel, geographic location, local infrastructures and capabilities, then it is unlikely that the technology can be transferred as a turnkey project or through material means only. CCS technology transfer will therefore need to encompass all the different types of transfer practices discussed in the previous section, in order for it to be successfully deployed at the global scale set out by the IEA's CCS roadmap for climate mitigation (2010), and this is a key reason why difficulties were experienced with implementing CCS in India during the study period 2007-10 (see Chapter 7).

2.4 Technology, Politics and International Relations

Given that technology is a social construct and its development inevitably involves large number of interests, then it can be assumed that politics lies at the heart of technology. In the same vein, technology reflects the type of society we live in today, and is central to the overall global political system, playing a key role in security, trade and culture. Moreover, large technological systems such as nuclear weapons, fossil-fuel energy, transportation networks and information technology have been developed by states with repercussions far beyond their own national borders. Hence there is a very strong international dimension to technological change (e.g. Talalay et al. 1997; Abraham 1998; Herrera 2006; Bridge et al. 2013). The reciprocal relationship between technology and politics is a crucial element of the conceptual framework of this thesis. This section explores a growing area of interdisciplinary scholarship that combines the fields of International Relations and International Political Economy (IR/IPE) with STS concepts, and which discussed and analyses the key geographical relationships necessary for technology transfer.

2.4.1 Technology & Politics

> *"… technology matters to IR/IPE because it alters state power and adds to the agenda and instruments of state policy – not the least because it changes the competitiveness of nationally based sectors of economic activity." (Talalay et al. 1997, p. 3)*

Even though a very large body of IR and IPE scholarly work implicitly recognizes the importance of technology and technology-related policies, it is increasingly being criticised for its traditional portrayal of technology "as an external, passive, apolitical, and residual factor" to international relations or global affairs (Fritsch 2011, p. 27; Talalay et al. 1997; Herrera 2006; Sylvest 2013). Fritsch (2011, p. 28) argues that:

> *"… standard explanations of systemic changes in global affairs usually focus on political or economic variables, neglecting technology's core role as a driving force behind systemic transformation as well as its reciprocal relations with politics, economics, and culture." (Ibid.)*

Similarly, Talalay et al. (1997, p. 2) acknowledge the "potent" role of technology, and even though not entirely ignored, it has been "explicitly analysed in a specific and narrow way" and primarily "treated as an exogenous and given factor – and hence all too often 'black boxed' – and at the same time largely to be viewed as instrumental – as a tool or as an object of policy". This approach is particularly prevalent in security studies looking at technology in terms of weapons, war and military power (McNeil 1982), "with the associated danger of arriving at explanations/analyses from an implicit technological determinism" (Talalay et al. 1997, p. 2).

Conversely, within the STS literature discussed in Section 2.2 technology is considered to be a key actor that is endogenous to the system and a constitutive factor. However, it has been argued that the STS approaches to innovation and sustainability transitions do not give explicit attention to the political dimensions of such systems

(Meadowcroft 2011). Meadowcroft (2011, p. 73) calls for political scientists to better engage:

> *"So far sustainability researchers have focused largely on policy: what it is and what it could/should be. For example, there must be thousands of academic articles on the design of climate policies and instruments. However, much less attention is devoted to the political circumstances that make the adoptions of such policies likely." (Meadowcroft 2011, p. 73)*

Political scientist John Street's (1992) analysis highlights the "inseparability of politics and technology" and links technical change with political processes (*Ibid.*, p. 3). He also links technological change with the theory of political choice, where the *need*, be it general human needs or those of a political interest, determines the reason why the technology gets developed in the first place (*Ibid.*, p. 37). Furthermore, Street's analyses draws attention to the intimate relationship between the state and technology, where the state plays the role of the 'customer', the 'regulator', or the 'underwriter' (*Ibid.*, p. 49). All three are very important roles, especially for technology transfer, and more specifically the transfer of a large, complex and capital-intensive technology such as CCS.

As the 'customer', "the state plays an important role in purchasing and introducing technology, and this can effect both the state's operation and the character of available technologies" (*Ibid.*, p. 53). This point is important for traditional technology transfer, where developing countries are in essence the 'customers' of technology from developed countries. Historically, there has been a "technological dependence on industrial technologies from the advanced, rich countries, from which the emergent nations needed to acquire modern know-how and technology as green revolution cash crops, hydroelectric power stations, and irrigation systems" (Josephson, 2006, p. 181).

As a 'regulator', states have an impact on the operation of the technology, and therefore states would play a very significant role in the implementation or transfer of CCS, particularly in terms of integrating the technology into existing energy frameworks (GCCSI 2012). Moreover, given the strong and historical "connection between government funding and technological development", the state has a significant role as the 'underwriter', providing the "resources for research which would be too costly for the individual corporations to bear" (Street 1992, p. 54). In the context of CCS technology, the state acts as the underwriter not only in terms of funding R&D, but also for taking on the liability for long-term storage (GCCSI 2011). It should be noted that these particular roles vary between and within nation states. Generally, developing countries are marked by their lack of funds to support vigorous R&D, so most of technology innovation and development takes place *outside* the country. Therefore, historically, technology transfer has involved turnkey projects.

Going further into detail, Street (1992) puts the role of a state in the context of 'political structures of control'. The example of the Soviet system's resistance to technical change in the Cold War era (1947-1991), has close similarities to India at the time (see Mehrotra 1990). Notably, India 'unofficially' aligned itself with the Soviets during that period[21], which was marked by the 'Hindu rate of growth' and bureaucratic stagnation (Balasubramanyam 1973; Abraham 1998). Like the Soviets, this resistance to technical change was due to "a result of the barriers it created to internal and international competition" (Street 1992, p. 56), which hampered indigenous innovation. His example of the Soviet Union suggests that "a political structure which excludes economic competition or political pluralism is liable to have a technology policy dictated by particular interests" (*Ibid.*, p. 58).

However, although it is true that innovation 'thrives best in a free and open society' (*Ibid*., p. 57), Street argues that it depends on the technology. For example, the "lack of central coordination can lead to the underdevelopment of technology policy" (*Ibid*., p. 58), such is the case for large and complex technologies such as nuclear technology, and is also important for implementation low carbon technologies such as CCS (Walker 2000; Mallah & Bansal 2010; Sovacool & Valentine 2010; Ockwell & Mallet 2012). Moreover, Street adds, "centralism may be conservative in the form of technology that is adopted, but it provides for decisiveness in the face of potential political

[21] Notably, the India-Soviet Union link is an important aspect of India's energy history, and influences the current structure if India's energy system. This is discussed in further detail in Chapter 5.

unpopularity” (Street 1992, p. 59). Therefore, the approval and cooperation of the state is paramount for any form of CCS technology transfer.

2.4.2 Linking IR and STS Theories

There have been a few notable studies that have recognized the fundamental and reciprocal relationship between technological change and politics (e.g. Street 1992) and thereby international political change and the global system (see McNeil 1982; Talalay et al. 1997; Herrera 2006; Fritsch 2011; Sylvest 2013). For the context of this thesis, the emphasis in this section is on a particular subset of IR scholars that focus on technology. Specifically, recent analysis by Herrera (2006), Fritsch (2011) and Sylvest (2013) has linked IR theories with STS approaches. These scholars have used a ‘systems approach’ to IR scholarship, as demonstrated in STS perspectives, and describe the relationship between technological systems and the international system to be “mutually constitutive” (Herrera 2006, p. 7), where technology is “an endogenous and political factor that is deeply embedded into the global system” (Fritsch 2011, p. 28). These studies draw upon the constructive approaches to technology, and argue that the sociotechnical systems approach should be integrated into the “theoretical conception of the international system” (Herrera 2006, p. 26). This would strengthen IR scholarship because, “technological change can induce changes in the nature and distribution of power within the system, but systemic level and state level factors shape technological change” (*Ibid*., p. 195).

The focus of these studies is on mature, large technological systems and systemic change, using examples such as railroads and the atom bomb (see Herrera 2006), and largely draw upon the seminal work of Thomas Hughes (e.g. 1983; 2004) and the Large Technological System (LTS) concept for bridging the fields of IR and STS (Sylvest 2013, p. 134). Fritsch (2011) describes this connection:

> *"Technological systems are based on networks in which technological artifacts, individuals, organizations etc. become interacting entities. With regard to global affairs, certain weapons systems (nuclear weapons), as well as communication, transportation, and energy systems might qualify as particularly relevant. Their distinct qualities, such as their network character, their tendency to diffuse globally over time, their vital backbone function in global economics, security, and culture, and particularly their impact on time-space compression in global social relations make them so relevant for any in-depth exploration of the mutual relationship between technology and global affairs." (Fritsch 2011, p. 33)*

Although STS theories are good at 'opening up the black box' and explaining the drivers behind technological change, Sylvest (2013, p. 135) argues that "existing LTS studies tend to focus more on system builders and success stories than on stasis and failure, and the development of national infrastructure systems (for example gas and electricity) is a classic object of study in the field," and therefore "LTS research risks confining itself within national or functional borders". Furthermore, Slyvest points out that "only rarely are technological systems approached from a viewpoint that combines security and sustainability", which is a gap that IR/IPE scholarship could address (*Ibid.*).

Interestingly, these analyses have not explored the MLP framework, which builds upon the LTS concept and has been applied more widely in the context of sustainability transitions (see Section 2.2.4). This may link in with the argument presented earlier that the wider global context lies within the landscape level, and is therefore considered to be exogenous to the system. Moreover, the MLP is quite a structured framework, with distinct levels, which may be too prescriptive for interdisciplinary approaches by the IR/IPE community. Therefore, for clarity, the generic term of '*sociotechnical system*' is used throughout the thesis. This is because there is overlap/cross-over between LTS and MLP concepts, and therefore, 'sociotechnical system' encompasses both of them.

IR political theories can be broadly divided into three key schools of thought – realism, liberalism and constructivism (see Brown & Ainley 2009; O'Byrne & Hensby 2011). Given the significant roles of the state in the CCS sociotechnical system, e.g.

‘customer’, ‘regulator’ and ‘underwriter’ (see Section 2.4.1; Street 1992), the area of IR scholarship chosen to provide insights throughout the thesis is from the *Realist* tradition, in which states are the main actors. Political realism is a very wide-ranging field in itself, rooted in the “assertion by the Enlightenment English political philosopher Thomas Hobbes that humans are, by their very nature, sinful, violent and committed to self-preservation” (O’Byrne & Hensby 2011, p. 178; also see Morgenthau 1948; Talalay et al. 1997; Brown & Ainley 2009). When the realist perspective is applied to domestic politics, the world is considered to be without social control, or, in a state of ‘anarchy’, and order and control is achieved by the “presence of a strong state and the rule of law” (O’Byrne & Hensby 2011, p. 178). Given this premise of conflict and “on the intrinsically violent nature of humankind” (*Ibid.* p. 179), in the field of IR, traditional proponents of realism are often portrayed as military strategists, e.g. Morgenthau (1948) and Kissinger (1969). Therefore, the realist understanding of international politics is where “interstate relations are defined by fierce interstate competition over power and influence” (Fritsch 2011, p. 35). However, the fundamental message of realism in IR scholarship is not solely about conflict, but rather, more to do with competition and states always acting to ‘preserve themselves’ (Brown & Ainley 2009, p. 42; O’Byrne & Hensby 2011). In other words, a state’s priority is to design its foreign policy in order to protect its national interests, where technology can play a significant role (see McNeil 1982). This is reflected in the seminal work of Kenneth Waltz (1979) (often referred to as a *neorealist*), which takes a more systems approach to IR. A key aspect of realism/neorealism is that technology is viewed as an instrument to achieve power within the international system:

> *“The hierarchy among states is the result of the system-wide distribution of power, which itself is the result of the distribution of capabilities. The emphasis lies on states’ relative equipment in various power categories. Although not explicitly mentioned, technology implicitly represents one of those capabilities.” (Waltz 1979, p. 131; summarised in Fritsch 2011, p. 35)*

Notably, realist/neorealist tradition deals with issues at the macro-level, e.g. national security, accumulation of power etc., therefore political forces are considered to be more influential and dominant than technology in the international system (Waltz 1979, p. 173). Consequently, realists/neorealist largely view technology as “a passive, neutral, and exogenous instrument" (Fritsch 2011, p. 36). Scholars Herrera (2006), Fritsch (2011) and Sylvest (2013) consider this narrow conception of technology to be key weakness in IR interpretations of technological change. This perspective of technology as a 'passive force' "tends to neglect the reciprocal relationship between technological evolution and structural change in world politics" (Fritsch 2011, p. 36). Nevertheless, the realist lens is useful to point out the central role of the state for the development and regulation of large sociotechnical systems such as transport and energy networks. Furthermore, IR's realism/neorealism can strengthen STS perspectives by adding a 'global dimension' to approaches examining diffusion, or transfer, of large sociotechnical systems (Sylvest 2013, p. 122).

For a technology such as CCS, where the state has a pivotal role, political interests become paramount in its development. CCS also has a sociotechnical mixed identity, where it is inextricably linked to large and mature technological systems. Given these conditions, both IR and STS interpretations of technology provide useful insights for analysing India's rejection of CCS implementation during the study period (2007-10). The two core perspectives are summarised in Table 2.3 below, including their strengths and weaknesses. This summary table incorporates relevant elements from the literature discussed in this chapter, using both STS and IR concepts (e.g. technology realist/neorealist and sociotechnical systems), to form the basis of the interdisciplinary approach used to analyse the empirical evidence in this thesis. For clarity, the political frame used for analysis in the empirical chapters will be generally referred to as '*technology politics*' (with a realist lens). This term also broadly refers to the collection of IR scholars that specifically examine the inherent relationship between international politics and technological change (e.g. Talalay et al. 1997; Herrera 2006; Fritsch 2011; Sylvest 2013).

Table 2.3: Summary of key analyses from the literature, including IR realist interpretations of technology, and specifically for mature sociotechnical systems (largely based on work of Herrera 2006; Fritsch 2011; Sylvest 2013).

Theory	***Main Actors***	***Core Thinking***	***Strengths***	***Weaknesses***
Realism/ neorealism *(IR/IPE scholarship)*	States	• Redistribution of power between states • Interstate relations defined by competition over power & influence • Technology is a military power source or economic power source (i.e. state capabilities) • No centralized power • State v State; self-interest in anarchical realm of international politics	• Acknowledges "the material underpinnings of global society, in the form of perceived needs (survival, prosperity), as well as the role of interstate competition for power and influence as the major driving force behind technological evolution" (Fritsch 2011: 36). • "Correctly points to the central role of the state for the development and global/national governance of technological systems" (*Ibid.*). • Especially relevant for large technological systems because "national governments often provide vital initial resources" (*Ibid.*).	• Technology seen as "a passive, neutral, and exogenous instrument" (Fritsch 2011: 36). • "…tends to neglect the reciprocal relationship between technological evolution and structural change in world politics" (*Ibid.*).
Socio-technical systems *(STS scholarship)*	Mature Technologies; States; System-builders	• The "technological system can be both a cause and an effect; it can shape or be shaped by society. As they grow larger and more complex, systems tend to be more shaping of society and less shaped by it" (Hughes 1990: 51) • "…technological systems have life cycles. Different development stages generate different impacts on the system and units" (Fritsch 2001: 35)	• Links well with entrapment & lock-in theories, especially when sociotechnical systems mature • Space and time are key aspects of the assessment of technological change, where constructivist arguments used to describe new technologies, and determinism used for mature technologies (Street 1992).	• STS research tends to confine itself within national or functional borders – i.e. lacks the international dimension, and how technological systems affect global systems (Sylvest 2013: 135) • Too focused on construction processes & user perspectives (*Ibid.*) • Security, welfare and sustainability largely absent from LTS literature – combining these issues has more relevance for developing countries.

Given the multiple actors and geographies involved in CCS technology development, de Coninck & Bäckstrand (2011, p. 368) applied IR theories to CCS politics and to "explain the growing diversity, overlap and fragmentation of international organisations dealing with CCS". When viewed through the realist lens, de Coninck & Bäckstrand (2011, p. 375) observe that the main proponents of CCS within the international arena are dominated by fossil fuel states (e.g. Australia, Canada, EU/UK, USA). Furthermore, the realist understanding of CCS politics assumes that international organisations 'lack teeth' in terms of enforcement and regulation (*Ibid.*). Therefore, the emphasis is on states; international organisations are not independent from state power and cannot influence preferences of sovereign states (*Ibid.*).

In addition, when considering international technology transfer and development, a strong *geographical* dimension is added to technological change. Consequently, there are also *geo*political aspects to consider, which highlight "geographic factors as important determinants of government policy and major determinants of the relative power position of states" (Verma 2007, p. 3282). The geopolitical approach in IR scholarship "stresses the importance of locational factors in influencing relations among nations" (*Ibid.*), and demonstrates "how the uneven distribution of natural resources acts as a major source of global insecurity" (Dannreuther 2007, p. 77). Therefore, IR theories embracing politics provide a useful complement to more industry and production-focused STS theories (Sylvest 2013). When used in combination, STS and IR will allow for a fuller sociotechnical analysis of CCS in the Indian context.

2.5 Conclusions

Technology is a social construct, and therefore the conceptual framework for this study is multidisciplinary, drawing upon theoretical concepts from social science literatures in order to gain insights for understanding technology development that goes further than the customary science and engineering perspective. The review in this chapter largely pertains to theoretical concepts from STS, with insights relevant to technological change and development, particularly associated with major societal transitions. With its social constructivist roots, STS scholarship has been most applied to the development of emerging technologies and their early stages of innovation. However, the sociotechnical systems concept, which deals with mature technological systems, seems to be a more appropriate fit for certain CCS technologies. This interpretation allows the view of CCS as a collection of incremental innovations. Though, some aspects of the CCS chain could be considered as radical innovations, depending on its use. Notably, CCS is not a single technology and it also has multiple potential objectives, such as EOR, hydrogen production and climate mitigation. Therefore, a key insight from the review in this chapter is that CCS has multiple and mixed sociotechnical identities, and STS frameworks embrace such mixed identities and social interpretations of technology.

Notably, STS theories lack explicit attention to the international dimension, which is a key part in an increasingly globalised world, linked through trade and technology transfer. Furthermore, historically, there has been a flow of modern technology from industrialized nations to the developing world. This technology transfer process is essentially part of the legacy of colonization and imperialism and, therefore also needs to be considered in the context of this case study exploring CCS in India. Interestingly, the review of the STS literature shows that the empirical base is largely concentrated in developed countries, and notably for CCS, in those states specifically that have established experience and expertise with fossil fuel extraction and exploitation. Therefore, ideas about technology transfer help develop the 'geography' and contextual gap in STS, with their focus on developing countries.

Given that current CCS innovation and R&D, i.e. the step that precedes technology transfer, is taking place in specific industrialized nations, it is important to explore the technology transfer process to developing countries from the development studies literature. The review indicates that due to the complexity of CCS technology, it cannot be transferred as a turnkey project, which has been the traditional method of technology transfer to developing countries. Furthermore, certain low-carbon technologies have additional specificities, because they are yet to be commercially developed and implemented. CCS in particular is at this stage, and therefore the technology transfer process will be more complex, requiring a combination of material, design and capacity transfer processes. This implies that the country receiving the technology should also be involved in the R&D process in order to meet country-specific conditions.

Consequently, the state has a very crucial role within technology transfer processes, playing the role of customer, regulator and underwriter. Given the political processes associated with states, which are key actors within technological systems, there is a reciprocal (i.e. mutually constitutive) relationship between technological change and structural change in global politics. However, this reciprocity has been under-represented in both STS scholarship and IR/IPE perspectives, even though technology is inherently political. Politics emphasises the importance of the state, which is useful for analysing sociotechnical systems. This has specific relevance to mature sociotechnical systems because they tend to be more affected by top-down policies and established interests. Therefore, an interdisciplinary approach combining concepts from STS and IR theory can provide an appropriate conceptual framework for CCS technology transfer to other countries. This combined approach is particularly of greater relevance where the state has ultimate control on technology development. In addition, technology transfer between nations involves diplomacy and international relations in order to reach multilateral agreements that facilitate technology transfer. The interdisciplinary analysis drawing on two core areas from STS and IR scholarship, e.g. sociotechnical systems and technology politics, is used throughout all of the empirical chapters (Chapters 4, 5, 6 and 7) to explore the research questions regarding why CCS was not adapted in India in the period 2007-10. A more detailed discussion on interdisciplinary research can be found in the following chapter, which outlines the approach and methods used for gathering empirical evidence.

Chapter 3: Research Methods

3.1 Introduction

This chapter explores the qualitative research methods used to collect and analyse data for this thesis. In order to facilitate research involving multiple disciplines, a research design that is flexible and accommodating of a variety of tools for gathering data was applied. Given the research questions outlined in Chapter One, combined with the theoretical framework discussed in Chapter Two, the case study method was thought to be most appropriate for this study. This is because the case study is an holistic approach and suitable for interdisciplinary research in particular. Accordingly, Gerring (2007) argues that much of what we know about the empirical world has been generated by case studies, and case studies continue to constitute a large proportion of the work generated by the social science disciplines. Hakim (2000, p. 59) describes the case study as the "social research equivalent of the spotlight or the microscope: its value depends crucially on how well the study is focused." Furthermore, a case study is typically considered "as the intensive study of a single case where the purpose of that study is – at least in part – to shed light on a larger class of cases" (Gerring 2007, p. 20). This is because the case study allows the researcher to blend various research methods, and in particular, there is a strong overlap with other types of qualitative studies. It is also to do with the ability of case studies (because of their detail) to help develop theories and concepts, which can then be tested elsewhere. This attribute is crucial when dealing with the many facets of technological change and development, including the complexities that characterise a developing country.

In the context of this study, there are essentially two case studies. First, there is the broader case study that explores why the attempted transfer of CCS technology to India did not occur during the study period. Second, there is a smaller case study on the Cambay Basin, which sits within a wider Indian CCS case study. These case studies allow exploration of the research questions, and provide some wider insights on the far-reaching implications of international politics on low carbon technology development.

The tools used to gather data are discussed in Section 3.1. In addition, a discussion on the role of the researcher and how this influenced data collection is presented in Section 3.2. The evolution of this project and the practicalities of doing research with multiple disciplines is explored in Section 3.3.

3.2 Data Collection

The flexible nature of case study research allows the use of a variety of data collection techniques, giving a more rounded, holistic view than with any other research design (Hakim 2000; Marshall & Rossman 2006; Gerring 2007; Moses & Knutsen 2007). Some of the data gathered at times was technical, i.e. pertaining to geology or engineering, in keeping with the sociotechnical analysis used within the thesis (see Chapter 2). The following sections describe the techniques used for collecting data for this study, which are commonly employed in the fields of anthropology, sociology, history and political science and STS. These include participant observation, in-depth interviews, a survey, and unobtrusive measures for further triangulation.

3.2.1 Fieldwork: participant observation

Gerring (2007, p. 20) states that "an *observation* is the most basic element of any empirical endeavour" and, participant observation is a key method for gathering data in qualitative studies. Participant observation requires first-hand involvement and, can be described as a method in which "the observer participates in the daily life of the people under study, either openly in the role of researcher or covertly in some disguised role, observing things that happen, listening to what is said, and questioning people, over some length of time" (Becker & Geer 1969, p. 322). Therefore, ideally, the researcher needs to spend a significant amount of time immersed in the setting, in order "to hear, to see, and to begin to experience reality as the participants do" (Marshall & Rossman 2006, p. 100). Moreover, the accuracy of information gathered through interviewing is highly dependent on the researcher's ability to infer and interpret certain processes. Therefore, participant observation allows the researcher to fill in the 'gaps' and is complementary to other social science methods, allowing one to collect any details that may pass unnoticed in an interview (Becker & Geer 1969; Marshall & Rossman 2006).

Consequently, the A5 notebook and pen was the most essential piece of 'kit' I required in the field, as crucial observations that added detail or context to interviews could be made during events or immediately after and reduce the risk of miss-interpretation of the topic discussed.

The fieldwork for this research project was conducted primarily over three trips, which were all based around key events, such as conferences, workshops and specialist meetings (see Table 3.1). In most cases, I was speaking or presenting posters at events, giving me an opportunity to network and build relationships with a variety of professionals. Although the majority of the fieldwork was set in India, time was also spent interacting with Indian delegates in international settings such as the Greenhouse Gas Control Technologies (GHGT) conference in Washington DC or the UN climate negotiations in Copenhagen. The first two trips were primarily based in New Delhi, and the last trip was at the UNFCCC COP in Copenhagen, where I observed climate negotiations, as well as specific negotiations regarding CCS under the CDM (see Chapter 6). The time spent in the field varied, depending on the duration of the workshop or conference and, at times external events influenced the length of time that could be spent out in the field. For example, the first trip to India lasted nearly three months, where TERI was kept as a base, and interviews could be set up on an ad-hoc basis or, at times serendipitously due to being locally based. The second trip to India was meant to be of a similar duration, but was cut short due to the deadly terrorist attacks in Mumbai in November 2008. The impact this event had on the research itself is briefly discussed in Section 3.2.5.

The network of contacts built over the first two field trips was used as basis for a selective stakeholder survey, described in Section 3.2.3, which was conducted in 2009, prior to the last field trip in Copenhagen. The first two field trips were crucial, not only for getting to know who the main actors were in India, but also getting to interact with other interested parties, such as representatives of large multinational companies (MNCs). These individuals tended to be technical experts from countries who had an economic interest in developing CCS, i.e. the UK, USA, Canada, Australia and Norway. These companies not only had an interest in India as a potential market, but their representatives were also a useful resource, or 'informants', as they directed me towards their Indian counterparts who would not have necessarily attended some of the events outlined in Table 3.1. Section 3.2.2 includes a list of such informants[22] (see Table 3.3.), and further discusses their role.

A crucial element of participant observation is the personal reflections of the researcher, who once immersed in the setting of study, has “the opportunity to learn directly from his [or her] own experience” (Marshall & Rossman 2006, p. 100). Therefore, it is essential to consider “the role or stance of the researcher as a participant observer – her positionality” (*Ibid.*). My role specifically in the context of the fieldwork is discussed in Section 3.3.

[22] It should be noted that the term ‘informants’ has traditionally been used in the methodology analyses literature (e.g. Dexter 2006). However, more recent discourse on the subject is not comfortable with the use of the term to refer to people who are sources of information, due to its “sinister connotations” (Rossman & Rallis 2012, p. 160). For example, Rossman & Rallis (2012, p. 160) “do not see key sources of information and insight as spies or turncoats,” and therefore “invite suggestions for a new term for this role.” Nevertheless, for the purposes of this thesis, the traditional terminology will be used.

Table 3.1. Fieldwork trips made during the course of this study, including key events and research activities for collecting data.

Field Trip No.	*Dates*	*Location*	*Key Events*	*Main Activities*	*Interview Codes*
1	Jan – Mar 2008	New Delhi, (based at TERI); India	• EU Commission – India Working Group meeting on clean coal • DEFRA/British High Commission CCS workshop • Delhi Sustainable Development Summit (DSDS)	• Reconnaissance • Network-building • Participant observation • In-depth interviews	• A1 • A2 • B1 • B2 • B3 • B4 • B5 • B6 • C1 • C2
2	Nov – Dec 2008	Washington DC, USA; New Delhi, India	• IEA's GHGT9 conference, (Washington) • EU Commission – India Working Group meeting on clean coal	• Network-building • Participant observation • In-depth interviews	• B9 • B10 • B11 • C3
3	Dec 2009	Copenhagen, Denmark	• UNFCCC COP15	• Participant observation • In-depth interviews	• B12 • B13 • B14 • B15 • B16

3.2.2 In-depth Elite Interviews & Informants

Interviewing is one of the most common tools used for gathering data in the social sciences, and it can range from the standardised or formally sampled and structured, to the non-standardised, open-ended and more informal format. The interviews conducted for this research are largely semi-structured and exploratory in nature, also referred to as in-depth interviews. These interviews “typically are much more like conversations than formal events with predetermined response categories”, in other words, “a conversation with a purpose” (Marshall & Rossman 2006, p. 101). For the more technical interviews, e.g. regarding a specific oil field in the Cambay basin, extensive preparatory background work was done in order to provide a set of questions in advance, indicating the kind of information required (see Cairn interview guide in Appendix D).

For other general interviews, particularly with policy makers, an initial broad ‘theme’ was used to initiate discussion, such as ‘India’s energy sector’, or for those interviewees met at a workshop, then the theme would be more specific to ‘the overall potential of CCS technology in India’. A few open-ended questions to get the interview started were sent to the participants prior to the interview, for example, ‘what are your views regarding CCS technology?’ or ‘what are the main issues regarding India’s energy sector, and how does India plan to address them?’ However, it should be noted that the ‘opening questions’ depended on who was being interviewed and, the context in which we had made contact. Such planned interviews tended to be with Indian Government officials, and largely took place during the first field trip (see Table 3.1 and Table 3.2). Some interviews, such as those with security professionals were regarding energy security issues specifically to a certain topic connected with the CCS technology chain, e.g. interviews with the Indian police services on coal or electricity theft, and Indian Naval officers were asked to comment on the shipping of hydrocarbons. Therefore, their questions were different, but still, a broad and exploratory tone was maintained in order to initiate conversation, (e.g. what are the main security concerns regarding the supply of coal in India?). In some cases, initial planning was not always possible, as some interviews were serendipitous encounters, which then required quick thinking, e.g. those at the UNFCCC COP15.

Table 3.2. Detailed list of interviewees and their organisations.

Elite Type	*Position*	*Organisation*	*Sector*	*Date*	*Location*	*Interview Type*	*Reference Code*
Political	Minister	Ministry of Science & Technology (MST)	Government of India	2 Feb 2008	New Delhi	In person	A1
Political	Minister	Ministry of Environment and Forests (MEF)	Government of India	15 Feb 2008	New Delhi	In person	A2
Professional	Director, Technology & External Affairs	Ministry of Power (MoP)	Government of India	11 Feb 2008	New Delhi	In person	B1
Professional	Director (R&D)	Coal India Ltd. (CIL)	Industry (GoI Enterprise)	11 Feb 2008	New Delhi	In person	B2
Professional	Policy Advisor	Centre for Rural Development (CRD)	NGO	12 Feb 2008	New Delhi	In person	B3
Professional	Director (Onshore)	Oil and Natural Gas Corporation (ONGC)	Industry (GoI Enterprise)	14 Feb 2008	New Delhi	In person	B4
Professional	Director (Exploration)	ONGC Videsh Ltd. (OVL)	Industry (GoI Enterprise)	14 Feb 2008	New Delhi	In person	B5
Professional	Chairman	Planning Commission of India	Government of India	27 Feb 2008	New Delhi	In person	B6

Elite Type	*Position*	*Organisation*	*Sector*	*Date*	*Location*	*Interview Type*	*Reference Code*
Professional	Director General (DG) (retired) Jharkhand	Indian Police Service (IPS)	Government of India	6 April 2008	-	Telephone	B7
Professional	Inspector (retired) Uttar Pradesh & Bihar	State Police Services (SPS)	Government of India	6 April 2008	-	Telephone	B8
Professional	Chief Design Engineer	National Thermal Power Corporation Ltd. (NTPC)	Industry (GoI Enterprise)	23 Nov & 13 Dec 2008	Washington DC & New Delhi	In person	B9
Professional	Executive Director	Power Finance Corporation Ltd. (PFC)	Industry (GoI Enterprise)	10 Dec 2008	New Delhi	In person	B10
Professional	Senior Advisor (CATs) – Climate Change & Energy Unit	UK Dept. for International Development (DFID) India	Government (Other)	11 Dec 2008	New Delhi	In person	B11
Professional	Special Envoy, Climate Change	Ministry of External Affairs (MEA)	Government of India	7 Dec 2009	Copenhagen	In person	B12
Professional	Senior Policy Advisor/Negotiator	Brazil	Government (Other)	9 Dec 2009	Copenhagen	In person	B13

Elite Type	*Position*	*Organisation*	*Sector*	*Date*	*Location*	*Interview Type*	*Reference Code*
Professional	Senior Policy Advisor/Negotiator	Grenada	Government (Other)	10 & 12 Dec 2009	Copenhagen	In person	B14
Professional	Senior Policy Advisor/Negotiator	United Arab Emirates (UAE)	Government (Other)	12 Dec 2009	Copenhagen	In person	B15
Professional	Senior Policy Advisor/Negotiator	Costa Rica	Government (Other)	16 Dec 2009	Copenhagen	In person	B16
Professional	Captain (Naval Attaché to Iran)[23]	Indian Navy	Government of India	19 Aug 2010	-	Telephone	B17
Professional	1st Mate/Chief Engineer[24]	Indian Merchant Navy	Government of India	30 Aug 2010	-	Telephone	B18

[23] Indian rankings of military personnel are the same as the British Armed Forces. Therefore, like the Royal Navy, Captain is a senior officer rank, equivalent to a Colonel in the British Army or Royal Marines.

[24] Indian Merchant Navy Officers follow the British System. The 1st Mate is the second in command to the Master, (or Captain), and is equivalent to Lieutenant Commander in the Navy.

Elite Type	*Position*	*Organisation*	*Sector*	*Date*	*Location*	*Interview Type*	*Reference Code*
Business	Director, Science & Technology	Schlumberger Asia Services Ltd.	Industry (Private)	28 Feb 2008	Gurgaon	In person (group interview)	C1
	Field Service Manager						
Business	Director - Subsurface	BG Exploration & Production India Ltd.	Industry (Private)	29 Feb 2008	New Delhi	In person	C3
Business	Head – Reservoir Development	Cairn Energy India Pty Limited	Industry (Private)	9 Dec 2008	Gurgaon	In person (group interview)	C3
	Senior petroleum engineer/geolo gist						
	Legal advisor - PSCs						
Business	Head of CO2 Shipping	A.P. Moller - Maersk Group	Industry (Private)	6 & 13 May 2010	London/-	In person/ Telephone	C4
Business	Chief Operating Officer	Univan Ship Management	Industry (Private)	7 & 19 May 2010	London/-	In person/ Telephone	C5

The interviewees listed in Table 3.2 represented a total of twenty-five organisations. Majority of the interviews were conducted in person, and any further enquires were followed up by email or by phone. Also, some of the technical interviews were not necessarily with an individual, but rather, a small group of specialists that could address my questions with the relevant expertise (e.g. interviews C1 and C3 in Table 3.2). The interviews ranged from brief 15-20 minutes to in-depth interviews that lasted for at least an hour or more, depending on the situation. For example, at the UNFCCC COP delegates are constrained by a tight negotiating schedule, therefore interviews had to be shorter. In contrast, some interviews in Delhi lasted for over two hours.

Discourse regarding CCS technology in India is exclusively within elite circles, and this is reflected by the list of interviewees in Table 3.2 (two political, eighteen professional and eight business elite individuals). The interviewees can all be classed as elite, or very important people, and can be divided into three broad categories: 1) professionals, traditionally having spent many years in education towards advanced degrees, such as law, medicine and academia; 2) business leaders or executives; and 3) community or political elites (Hertz & Imber 1995). In the context of this study, the majority of elite interviewees have specialist knowledge about CCS in India, or have been directly involved with the decision-making and/or political processes that have considered the suitability of this technology for India. The exceptions are from the security services, though their expertise on energy issues was useful for providing context to some challenges for India's existing energy infrastructure.

Elite individuals tend to be difficult to access due to their status and time constraints. In an interview, elite individuals generally take on the role of 'teacher', where they define what the problem or situation is, introducing their notions of what they regard as relevant (Dexter 2006). Paradoxically, elite individuals also expect researchers to know something and to have done their homework. Previous studies have shown that doing preparatory background work is essential for establishing the respect necessary for doing research with elites (Ostrander 1993). Often, this groundwork requires the building of a network of 'informants', which is a common practice in development studies (see Desai & Potter 2006; Rossman & Rallis 2012).

Informants are knowledgeable and well connected individuals that demonstrate the "capacity to adopt the standpoint of the investigator" (Dexter 2006, p. 20). It should be noted that informants were not interviewees themselves, and there is no overlap. Informants and their organisations, listed in Table 3.3, gives an indication of the kind of institutions that had an interest in CCS implementation in India.

Table 3.3. Organisations comprising 'informants'.

Informants	
Sector	*Organisation*
Government	• British High Commission India • European Commission • UK DEFRA • UK FCO • UKTI • US EPA
Industry	• Alstom • Camco • Cairn Energy • Doosan Babcock Energy • ERM • Statoil
NGOs	• Carbon Capture & Storage Association (CCSa) • Energy research Centre of the Netherlands (ECN) • Global CCS Institute (GCCSI) • International Energy Agency GHG R&D (IEAGHG) • Imperial College London • The Energy Resources Institute (TERI) • University of Nottingham • University of Regina • United Nations University • World Bank • World Resources Institute (WRI)

Informants play a critical role by providing the researcher with information on forthcoming events, important protocol, further contacts or other informants that could prove useful. This study relied on the expertise of twenty-three informants (see Table 3.3.); these individuals assisted with access to elites or provided expertise to help me understand particular processes that I was not familiar with initially. This ranged from the technical intricacies of international climate change negotiations, to the particular skills required for dealing with India's immensely bureaucratic and hierarchical Ministries.

The literature discusses the importance of building a rapport with the interviewee that consists of both respect and trust (e.g. Ostrander 1993; Marshall & Rossman 2006; Dexter 2006; Hertz & Imber 1995; Lee 1993). Introductions from contacts aside, a researcher needs to be aware that gaining access is not the same as establishing the trust required for getting useful data, and should expect an ongoing process of being 'checked out' (Ostrander 1993). Therefore, generally the initial contact with potential interviewees always included my CV and a single-page summary of the project with the goals and objectives.

Interviews tended to be case specific: for example, an interview with an Indian Merchant Navy Officer was not on CCS, but more on the LNG trade route between India and the Middle East. Therefore, such interviews provided unique information that could be used to build a picture of that specific case study. General interviews on the prospects of CCS in India tended to complement each other, and rarely were there any major contradictions. This may be because the Indian Government had taken a unified position on CCS technology from the start, and their stance had an influence over other sectors, such as private industry (see Chapter 7). Also, at the time of this study, CCS was considered to be quite a sensitive topic in certain circles in India (see Chapter 6); therefore each participant was assured confidentiality, where the data would be anonymised prior to any interview, both verbally and in writing (see Lee 1993). Nevertheless, I also made it clear to interviewees that I would expect to draw upon the data collected in order to publish papers in professional journals. By setting these boundaries of my research, not only did I establish trust but, given the power of elite subjects, this was also a means for protecting the interests and integrity of the research and the researcher.

3.2.3 Survey: structure and respondents

A survey was designed to explore stakeholder views on the suitability of CCS for India and whether CCS could be developed and deployed in India if it was deemed to be appropriate for the Indian context. This was to triangulate my fieldwork, supplementing the observations and findings from participant observation and in-depth interviews. Moreover, the second fieldtrip was cut short due to unforeseen circumstances (see Section 3.2.5); therefore, it was judged that the survey was an alternative method for gathering data, which could be obtained electronically rather than in person. It should be noted that although surveys are a convenient method for exploring attitudes and beliefs of a group of people, the researcher relies "totally on the honesty and accuracy of participants' responses" (Marshall & Rossman 2006, p. 125).

Drawing upon a network of professionals built up over the course of two field trips in 2008, the survey targeted a wide range of stakeholders with different levels of experience and previous knowledge of energy and CCS in India. By the time the survey was conducted in May/June 2009, over half of the elite interviews had taken place in India (see Table 3.1). Many of the survey respondents were contacts that had been passed on by interviewees or informants. The survey consisted of three sections, composed of seventeen questions in total, and is included in Appendix A. It should be noted that the results of this survey were used as a basis for a working paper on CCS in India, commissioned by Christian Aid (see Kapila et al. 2009). A summary of the results is provided in Appendix B, and an overview of survey participants is presented in Appendix C.

The survey consisted of a combination of multiple-choice, ranking and open-ended questions, all of them giving participants the opportunity to express their expert opinion. The first section explored opinions on the importance of climate change and energy security for India. This section also asked for views on how energy and electricity supply in India might develop between now and 2050. The second section of the survey contained questions that explored viewpoints on whether CCS might have a role to play in India's energy landscape. This included questions considering more detailed issues around how CCS technology could be deployed if it was decided that it was a suitable technology to be used in the Indian context. Section three of the survey was primarily aimed at gathering information about the respondents in terms of their profession and focus area of work. This was done to allow analysis of any significant differences between perspectives of different stakeholder groups.

The survey was sent out to 65 individuals based in a wide range of stakeholder organisations in India, UK and the US. Regardless of the country they were based in, all individuals invited to participate were either working on, or had previously worked on, issues related to energy and India. The stakeholders were divided into two tiers, where tier 1 stakeholders were those who directly work on energy/environmental issues in India, and who would be affected by/or could influence any developments of CCS technology in India. Tier 2 stakeholders were those who at the time of the survey were not directly involved with work on energy/environmental issues in India, but either had been in the past and/or had an interest in how CCS could develop in India as it may affect their work in the future. The same proportion of tier 1 and tier 2 stakeholders were asked to participate in the research, with backgrounds ranging across academic institutions, private sector industry, Indian government, and international financial institutions (see Figure 3.1).

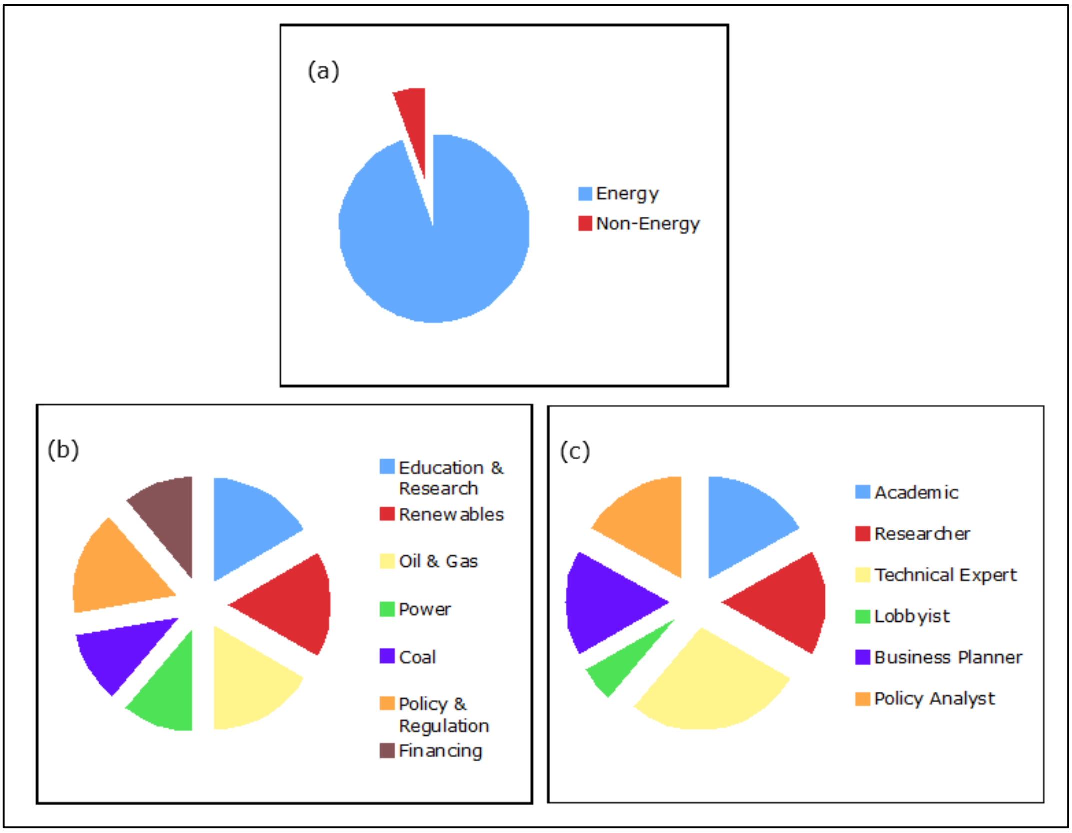

Figure 3.1: Background of survey participants in regards to (a) whether they work directly in the energy field, (b) the main focus of their work in the energy field, and (c) their profession.

Eighteen stakeholders (out of the 65 contacted), predominantly tier 1 and from the energy field, answered the survey, giving a response rate of approximately 28%. Steps taken to increase the response rate included follow-up emails, however many stakeholders responded that they lacked the time. The professions of respondents were fairly consistent regardless of the sector (e.g. industry, academic etc.) they worked in and were primarily researchers, policy analysts, technical experts, and business planners as illustrated in Figure 3.1.

3.2.4 Documentary analysis

In addition to the data obtained from interviews and the survey, analysis of documents was also used to understand the different contexts of the case studies (i.e. India, and specifically, Cambay). Data collection that involves gathering items such as documents or archival material is referred to as an 'unobtrusive measure' or ‘nonreactive research’ in the literature because it generally does “not require the cooperation of the subjects” (Marshall & Rossman 2006, p. 124). Notably:

> *“Unobtrusive measures are particularly useful for triangulation. As a supplement to interviews, nonreactive research provides another perspective on a phenomenon, elaborating its complexity.” (Marshall & Rossman 2006, p. 124)*

For the purposes of this study, key documents included publicly available Indian Government reports from the relevant ministries. Examples of such reports include a number of Working Group reports from the Ministries of Coal, Petroleum & Natural Gas, and Power that were submitted to the Planning Commission for the formulation of India’s Five-Year plans, specifically the 11th 5 year plan (2007-2012). In some cases, documents reviewed included brochures and company reports that were either recommended or provided by interviewees and informants.

In addition, primary sourced documents included international and national climate legislation, as well as negotiated text from various plenaries and working groups, which were all obtained during the UNFCCC COP but are also publicly available from the UN secretariat. Secondary sources were also used to sometimes corroborate or add further detail to the data obtained through interviews. These include NGO reports, research-based working papers, legal and academic commentaries, journals, and media articles.

3.2.5 Unanticipated shifts in research

Quantitative data pertaining to oil, gas or coal assets are not available publicly in India, as they are considered to be commercially sensitive and, in certain cases, of importance to national security. Initially, it was envisioned that technical information, such as composite well logs and other offshore data, could be obtained to characterise reservoirs and their CO_2 storage potential (e.g. see technical interview guide in Appendix D). However, permission to use such data lies with the Indian Government and not with individual companies that are operating the projects in designated areas offshore. Therefore, the original plan to have case studies based on a number of geological basins was not possible. A formal request was made to the Indian

Government to gain access to such information, but permission was not granted. As a result, the some technical aspects of the thesis are constrained to just one site, the Cambay basin, for which some of the data was obtained during a series of interviews. Even then, permission to use the data was limited to what was already available on the company website. This prevented any quantitative analysis, particularly in terms of CO_2 storage. Moreover, official geological or nautical maps of Indian offshore areas were not permitted to be used for this thesis. Therefore, maps used in Chapter Seven, depicting geological storage potential, are generated by the IEAGHG (2008) report, which analysed data provided by the Indian Geological Survey (using GIS[25]).

Notably, the second field trip to India started during the Mumbai terrorist attacks of November 2008. The attacks started on the evening of the 26th, and Mumbai was under siege till the 29th. These dates coincided with the EU Commission/Ministry of Power Clean Coal workshop (see Table 3.1), and during this period New Delhi was under curfew. The atmosphere was very tense and senior-level Indian delegates could not participate in the workshop as they were called into emergency meetings of state. Those present at the workshop were following the events in Mumbai and, as there were fears that the attacks may spread to Delhi, there was very little discussion on clean-coal technologies. On the second day of the workshop, the EU delegation, which I was considered to be a part of, was taken on an impromptu visit of a power station over 50km outside of the city. Therefore, the trip was cut short, and many of the interviewees were not interested in discussing CCS or any other energy related matters at that time. Some of the technical interviews with Cairn Energy on Cambay were not affected by this event, and they occurred as planned, though the attacks were a central point of discussion, particularly in terms of the security of India's energy infrastructure. Nevertheless, most of the other planned elite interviews were cancelled due to the attacks. Therefore, some of these were followed up at a later date over the phone. Others were invited to participate in the survey (as discussed in 3.2.3).

[25] Geographical Information Systems

3.3 The Researcher's Role and the Influence of Personal Biographies

> *"In qualitative studies, the researcher is the instrument. Her presence in the lives of the participants invited to be part of the study is fundamental to the methodology."* (Marshall & Rossman 2006, p. 72)[26]

With in-depth interviews, though "relatively brief but personal … the researcher enters the lives of the participants" (*Ibid.*). Therefore, this section discusses my personal characteristics, as the researcher, and how this has impacted my access to people and information. Researchers themselves draw from different social experiences and perspectives, and their personal characteristics such as gender, ethnicity, age, marital-status, class etc. will have an influence on the data collected. Understanding the differences in cultures of the researcher and those being researched is essential for successful fieldwork (Momsen 2006). Sometimes, these differences create unequal power relations in fieldwork relationships, where gender can eclipse the influence of other traits such as age, race or class (see Warren 1998; Momsen 2006).

Notably, there are certain aspects of who I am, i.e. female, (relatively) young and of mixed racial heritage, which influenced the way I conducted interviews. For example, my British nationality and predominantly Western upbringing, combined with my Indian heritage and fluency in several languages of the sub-continent, have contributed to a unique research situation. The colour of my skin and my fluency in Hindi and Punjabi not only helped in setting up New Delhi as a research base, but it also allowed me to interact with informants and elites in a multi-lingual and multi-ethnic context. Some interviews had an easy conversational flow, switching between English, Hindi, or Punjabi, depending on the individual. This process helped me build networks and gain trustworthiness with participants.

Furthermore, in the context of India, a hierarchy of authority and a polarization of gender dominate the culture. In my case, having family connections that were noted for

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[26] Emphasis added

their public service, my surname was well known within Indian Government circles. It can be argued that I was also considered as one of the 'elites'. Consequently, I gained access to certain senior officials, who are not readily accessible to most researchers. In a few instances, such interviews took place at the interviewee's residence, rather than the office, as I was the 'daughter/niece/grandchild of so and so, visiting from Scotland.' The informal settings actually put the interviewee at ease, and perhaps they tended to be more frank and open than they normally would have been. In addition, during the study period I was significantly younger than the predominantly male informants and elites that I crossed paths with; I was essentially assigned the role of a harmless adoptive daughter. Given my status or 'daughter' role, and New Delhi being quite a dangerous city for women, many of the interviewees provided for my safe travel to and from interviews, just as they would have done for their daughters[27]. This role aided my research because participants were in further ways willing to help, not only with contacts and useful information, but also to ensure that my fieldwork was safe and successful.

3.4 Thesis Evolution and Working with Multiple Disciplines

The original proposal for this PhD was prepared and accepted in 2007. Notably, around the time of the starting of this project (9th October), then Secretary of the Department of Business Enterprise and Regulatory Reform (BERR) of the UK Government, John Hutton, announced a competition for the demonstration of a CCS project in the UK. Specifically, this demonstration project had to be post-combustion capture on a coal-fired power station with offshore CO_2 storage (UK House of Commons 2007)[28]. Therefore, there was a keen UK interest in India, which relies on coal-based energy infrastructure. This background, combined with the circumstances discussed at

[27] Despite my insistence, I was generally prevented from using public transport. Though, eventually I managed to befriend a wonderful auto-rickshaw driver, Dubey-ji, who essentially became my trusted chauffeur and friend during my field trips.

[28] It was anticipated that the full CCS chain would be demonstrated by 2014, and it was expected that by this time 90% of the CO_2 emission from a 300MW equivalent generating capacity would be captured, as well as stored (See UK House of Commons 2007).

the beginning of Chapter One, influenced the original PhD proposal and research questions.

The funding was set up as a joint effort between two UK research councils, Natural Environment Research Council (NERC) and the Economic and Social Research Council; the grant was managed and administered by the UK Energy Research Centre (UKERC). Therefore, there was a requirement to combine disciplines of the physical and social sciences, in order to provide an interdisciplinary contribution. As a result, this project initially had three supervisors, each representing a different discipline each (geology, law and engineering). Such a supervisory structure was challenging, particularly as my three supervisors had not worked together before, and were located in different cities.

At the start, it was anticipated that, given the international momentum behind CCS at the time (see Section 1.1), India would be keener to collaborate, and there would be greater access to technical data[29]. This was because there was significant industry participation and research interest in the preceding years to the start of this project in October 2007. For example, in 2006 and the beginning of 2007, India's National Geophysical Research Institute (NGRI) in Hyderabad hosted workshops on CCS and R&D challenges, and there was a strong presence of UK academics at these workshops, including my principal supervisor Prof. Stuart Haszeldine. As a result, it was anticipated that further contacts for collaboration would be made at the joint workshop between the UK Department of Environment, Food and Rural Affairs (DEFRA) and the Indian Department of Science and Technology (DST), which took place in January 2008, and this formed the basis for the first field trip (see Table 3.1). Furthermore, The Energy Research Institute (TERI), based in New Delhi, was initially keen to collaborate with Edinburgh University and support this research. It was decided that TERI would form the research base in New Delhi, and Dr. Suresh Babu, an engineer with an interest in gasification technologies, was named as a third supervisor. In addition, as discussed in Section 1.1, there was plenty of activity in various international legal fora, therefore the second supervisor to show interest was an energy lawyer, Prof. Peter Cameron, based

[29] It should be noted that the author is a physical scientist by training, and came into this project with a background of both Undergraduate and Master's degrees in environmental geosciences and environmental chemistry, with specific experience in systems modelling.

at Dundee University. However, due to differences in interest and time constraints, I was left with a single supervisor by the end of my first year, Prof. Stuart Haszeldine, a geologist at Edinburgh University.

Given this background, the original plan was to have 2-3 case studies focused on specific geological basins with good storage potential, i.e. case selection was on the basis of geology. However, the constraints on access to technical data led to a more sociotechnical framing of the challenges to CCS technology transfer. Therefore, the thesis has evolved into a social science PhD, and the advisor for the social science aspect of this thesis is Dr. Heather Lovell, who is a Human Geographer. Significantly, the research questions had to be altered shortly after the research project was started, when it became apparent that the Indian Government was against CCS implementation in India. Rather than explore the potential of CCS in India, the research questions now focus on why the technology was not accepted as a viable option during the study period.

3.4.1 Interdisciplinary Versus Multidisciplinary Research

UKERC PhD projects were set out to be *inter*disciplinary. However, some of the difficulties I have had in framing my PhD are to do with the way it was set up as interdisciplinary. One of the challenges was having supervisors from completely different disciplines who didn't really know each other, and who were not in the same place. The interdisciplinary PhD is a widely used model now in academia to encourage academics to talk to each other and network, though the responsibility to manage these relationships generally falls on the student. Nevertheless, the interdisciplinary PhD is the future of academia, providing good training for an increasingly interdisciplinary academic environment, where researchers are encouraged to collaborate with external counterparts as much as with different departments within the same institution.

However, given that a *multi*disciplinary framework (see Chapter 2) forms the theoretical basis of this thesis, a distinction should be made at this point between interdisciplinarity and multidisciplinarity. Both forms of research approaches involve multiple disciplines, where generally there is the application of at least two disciplines towards a common research goal or set of questions (see Lawrence 2010; Baveye et al.

2014). The crucial difference between the two is that the interdisciplinary research process is more *integrative,* whereas multidisciplinarity has low integration between disciplines, which are working more in *parallel* (*Ibid.*). This distinction is described as follows:

> *"… like multi-disciplinarity, inter-disciplinarity involves several unrelated academic disciplines, each with their own contrasting research paradigms, but it does so in a way that forces them to cross subject boundaries. In the process of striving toward a common research goal, the concerned disciplines integrate disciplinary knowledge in order to create new knowledge and theory." (Baveye et al. 2014, p. 3)*

The difference is to do with the outcome of the research project. In the multidisciplinary setting, "neither discipline will be particularly affected in the long term by the interaction" required for answering research questions (Baveye et al. 2014, p. 3). Moreover, Baveye et al. (2014, p. 4) have discovered that often interdisciplinary projects "drift towards multi-disciplinarity," despite best efforts. This is attributed to the challenge that is integrative research, which involves bringing "together different epistemologies" (*Ibid.*). In other words, this requires "researchers to become immersed in one another's knowledge cultures, to understand the fundamental differences in their basic theories and axioms" (Tress et al. 2005 in Baveye et al. 2014, p. 3). Nevertheless, there is still a benefit of the multidisciplinary approach because, "each discipline adds new knowledge from its own perspective to complete the picture like pieces in a jigsaw puzzle" (*Ibid.*).

Significantly, in the overall context of this thesis, the perspectives and principles from STS and IR have been integrated in order to analyse the empirical evidence, and is therefore, interdisciplinary. Although the two core concepts of sociotechnical systems and technology politics were introduced in parallel in Chapter Two, they have been integrated throughout the empirical chapters (Chapters 4, 5, 6 and 7) to provide interdisciplinary insights. In other words, the whole is greater than the sum of its parts.

Interestingly, some of the technical information gathered from the interviewees perhaps may not have been gathered as easily if I were not a scientist to begin with. My background of the physical sciences allowed for me to network and build a rapport with technical specialists, whether it was a power plant engineer or a naval architect. Indeed, I would argue that interdisciplinary research is, in essence, an extensive linguistic exercise. Therefore, the learning process over the course of this study has been quite integrative. For example, I had the opportunity to take a number of LLM courses on international environmental law, specifically on climate and energy law, and law of the sea. This way, I learnt the language of lawyers and policymakers, which was excellent preparation for the UNFCCC COP. Whilst in the field at COP15, I was asked to brief country delegations on CCS deployment issues, and also asked to prepare a legal brief for a negotiator from a developing country (see Chapter 6). In order to familiarise myself with the literature of another discipline, again almost another language had to be learnt. As a result, having this 'multilingual' ability seemed to be a crucial attribute for doing interdisciplinary research. I would add that conversing with people from different disciplines was also one of the more enjoyable and very interesting aspects of doing interdisciplinary research.

3.5 Summary & Conclusions

Case studies allow for rich analyses, which can span multiple aspects, including the social and technical, and are therefore useful for interdisciplinary research. Data was collected by a variety of tools from the social sciences, including participant observation, in-depth elite interviews and the use of informants, a survey and review of official documents. The empirical evidence was gathered over three field trips; the first two were based in New Delhi, India. The first trip took place in the beginning of 2008 (lasting 3 months), and the second trip lasted roughly a fortnight towards the end of 2008. The latter trip had to be cut short due to the terrorist attack in Mumbai, as Delhi was under curfew whilst Mumbai was under siege. Notably, activities related to CCS technology were limited to specialised and elite circles of Indian society. This is demonstrated in the type of data gathered, where fieldwork predominantly centred on high-level events in the capital or in an international setting, and a series of elite interviews and a selective survey ensued.

Over the course of 2008, through networking at various events and making several contacts during fieldtrips, a network of Indian stakeholders was formed, and they were surveyed in 2009 to gather opinions of CCS technology and its potential in India. Out of the sixty-five surveys that were sent, eighteen responded, and this survey data, plus various official documents, are used to triangulate the interview material. It should be noted that although originally access to quantitative data was anticipated, in reality it was difficult to obtain permission from the Indian Government due to their stance on CCS, therefore the analysis is based on qualitative methods. Furthermore, personal characteristics, such as gender, age, background and ethnicity have had an influence on how and what data was collected.

The multidisciplinary theoretical framework discussed in Chapter Two is used for analysis throughout the empirical chapters (Chapters 4, 5, 6 and 7). Through the empirical case study, I seek to integrate the two core concepts together, and therefore the overall approach is described as interdisciplinary. Interestingly, the key to effective interdisciplinary research is to learn the 'language' of different disciplines, which helps not only with the interpretation of data, but also to engage with and gain access to a variety of information.

Chapter 4: CCS Technology

4.1 Introduction

The Carbon Capture and Storage (CCS) technology that is the focus of this thesis involves capturing carbon dioxide (CO_2) emissions from large point sources, specifically, fossil-fuel based combustion processes associated with power generation and industrial operations. The captured CO_2 emissions are then compressed and transported to be permanently stored within a suitable geological formation. It is important to note that the objective here is the permanent disposal of CO_2 for mitigation purposes, i.e. CO_2 is considered a waste product. Therefore, this conceptualisation of CCS technology involves three parts of a chain (capture, transport, storage), which are combined in an effort to reduce atmospheric emissions from large polluting sources.

However, as discussed in Chapter Two, technologies operate in a social, political and economic context. Therefore it is essential to consider both the social dynamics, as well as the technical, in order to understand how a technology is developed and transferred. Therefore, in terms of the sociotechnical perspective, how should we define CCS technology? Is it a radical innovation, consisting of a suite of new technologies that could create a technological revolution? Or is it best conceptualised as part of an existing large sociotechnical system, making it more of an incremental innovation? Or perhaps it is a combination of the two? The definition of the technology varies, as CCS is seen as something different by different groups of people. As briefly discussed in Section 2.2.2, countries such as the US refer to CCS as 'CCUS', where the focus of R&D activities also includes '*Utilization'* and storage of the CO_2 emissions, i.e. CO_2 is considered a commodity *and* a waste. Therefore, building upon the themes presented in Chapter Two, this chapter shows that CCS as a technology is still open to interpretation due to the multiple identities and flexible nature of the technology, making it a challenge to view it as a coherent sociotechnical system.

The different stages of the CCS chain and their technical aspects are presented in Section 4.2. The social dimensions of the CCS system are explored further in Section 4.3, highlighting some of the political dimensions and underlying commercial objectives, which also gives CCS a mixed identity, and this has implications for its transfer.

This chapter explores CCS technology through the sociotechnical lens because both social and technical aspects of CCS contribute to its mixed identity, as well as the subsequent failure to be transferred to India. Therefore, it can be argued that the way CCS was initially presented, or rather, defined, is a key reason for the unsuccessful technology transfer to India during the period of this study. Moreover, the political aim was to present CCS as a coherent technological system for climate mitigation, as another tool in the climate change toolbox. However, at the same time, there were strong underlying business objectives to this political endeavour, supported by the view of CO_2 as a commodity, or something that had market value.

4.2 CCS Technology: evolution & development

The prospect of CCS technology being used as a tool for climate change mitigation became popular during the first decade of the 21st century, the concept stems from earlier isolated academic research in geo-engineering in the 1970s and 80s. According to the historical review by Herzog & Drake (1996), the first conceptualisation of capturing CO_2 emissions from large point sources with the aim of isolating it from the atmosphere came from the work of Marchetti (1977). However, the research proposed during this period predominantly explored the permanent disposal of CO_2 in the deep oceans (see Marcetti 1997; Hoffert et al. 1979; Albanese & Steinberg 1980 cited in Herzog & Drake 1996).

The full CCS chain for mitigation began to take shape in the 1990s as a result of growing international concern regarding climate change. In 1991, Hendriks et al. from the University of Utrecht published their research on the option of CO_2 disposal in depleted gas fields, once captured from power plants and transported via pipelines. In the same year, the International Energy Agency (IEA) formed its research and development programme on greenhouse gas technologies (IEAGHG), based in Cheltenham, UK. Governments began to take notice of academic research in this area and during this decade the US Department of Energy (USDOE) supported a series of feasibility studies, conducted by the Massachusetts Institute of Technology (MIT)

Energy laboratory. These studies looked at various options for CO_2 capture and sequestration from fossil-fuel based power plants (Herzog & Drake 1996). This period essentially marks an increase in the coordination of R&D activities on CCS technology, whilst simultaneously there was a rise in political action over climate change. A timeline showing CCS research alongside international climate change related activities is presented in Table 4. 1.

At the turn of the 21st century CCS gained prominence in the global energy and climate agendas of several states, multilateral institutions and international organisations. The UK Government conducted its own feasibility studies during this period, with the notion to build capability for export. This is discussed in further detail in Section 4.3. Such activities at both national and international levels, coupled with the growing interest in CCS R&D, prompted the Intergovernmental Panel on Climate Change (IPCC) to conduct an assessment of the CCS literature in 2002, leading in 2003 to the commissioning of the IPCC Special Report on Carbon Capture and Storage (2005). India was not involved in any of these initial CCS discussions; India's engagement with international initiatives specifically on CCS started in 2006 (see Section 6.2.1).

The following sub sections explore in more detail the three different stages of the CCS chain: capture, transport and storage. It is important to outline these technical aspects of CCS in some detail because they have influenced how CCS has been perceived in India.

Table 4.1: Key stages regarding international climate change activities and CCS R&D activities since the 1970s (table content based on Herzog & Drake 1996; Birnie et al. 2009; table layout inspired by Evar et al. 2012).

International Activities on Climate Change	*Period*	*CCS R&D Activities*
	1970s & 1980s	• Initial stand-alone academic research & beginning of conceptualisation
• 1990: UN creates the Intergovernmental Negotiating Committee (INC); negotiations begin on climate treaty • 1992: The Rio Framework Convention on Climate Change is adopted by 143 countries (referred as UNFCCC) • 1995: Berlin hosts 1st Conference of the Parties (COP-1) to the UNFCCC; the Climate Technology Initiative (CTI) is formed, specifying the need for further research on longer-term technologies to capture and remove greenhouse gases	1990s	• 1991: IEA forms the IEAGHG, coordinating research on CO_2 capture, use and storage • 1992: University of Utrecht, The Netherlands, hosts 1st International Conference on Carbon Dioxide Removal (ICCDR-1) • 1990-1997: series of feasibility studies supported by US DOE
• 2005: G8 + 5 meeting at Gleneagles; target set to have 20 full-scale CCS demonstration plants by 2010 • 2005: UK-China bilateral agreement on Near-Zero Emissions Coal with CO_2 Capture and Storage (NZEC) programme	2000 – 2006	• CCS included alongside renewables to form a portfolio of green technologies considered for future energy & climate change plans • 2003-05: series of feasibility studies by UK DTI • 2005: IPCC Special Report on CCS technology
• 2007: Amendments made to London Protocol and OSPAR convention to enable offshore CO_2 storage • 2008: EU CCS Directive agreed by EU Council & Parliament • 2009: Amendment made to London Protocol allowing transboundary export of CO_2 • 2010: Agreement reached at Cancun COP16 to include CCS under the Clean Development Mechanism (CDM)	2007 - 2010	• 2007: launch of UK CCS demonstration competition • 2007: launch of NZEC initiative (Phase I) • **2008: 9th IEAGHG Conference on CCS, Washington DC** • **2008: EU Commission – India Working Group meeting on Clean Coal, New Delhi** • **2008: DEFRA & British High Commission International CCS Workshop, New Delhi** • **2010: 1st International CO_2 Shipping Conference, London**

NB: Items in **bold** indicate the event was part of fieldwork for this study

4.2.1 Capture

Herzog & Drake (1996), notably point out that initially the motivation behind CO_2 capture had nothing to do with the mitigation of greenhouse gases, but rather:

> *"… the idea gained attention because of the potential economic benefits of this source of CO_2, especially in enhanced oil recovery (EOR) operations in which CO_2 is injected into oil reservoirs to increase the mobility of the oil and, therefore, the productivity of the reservoir." (Ibid., p. 147)*

Their review states that a number of commercial CO_2 capture plants were set up during the 1970s, though due to the drop in oil prices in the 1980s the capture plants had to be closed because EOR operations were too expensive (*Ibid.*). Therefore, in this context, CO_2 capture technology by itself is an existing technological concept with an entirely different purpose. It can also be considered an incremental innovation, as it is used to augment fossil fuel production, and is therefore already part of an existing sociotechnical system, specifically, the sociotechnical system of oil and gas exploitation (i.e. the system includes exploration, production and distribution).

Currently three main design approaches are being developed to capture CO_2 from electricity generation based on fossil fuel or biomass: post-combustion, pre-combustion and oxyfuel combustion capture (see Figure 4.1). These approaches are generally viewed as being the most commercially advanced methods available for early deployment, where potentially 90% or more of the carbon emitted could be removed (IPCC 2005; Gibbins & Chalmers 2008; GCCSI 2011).

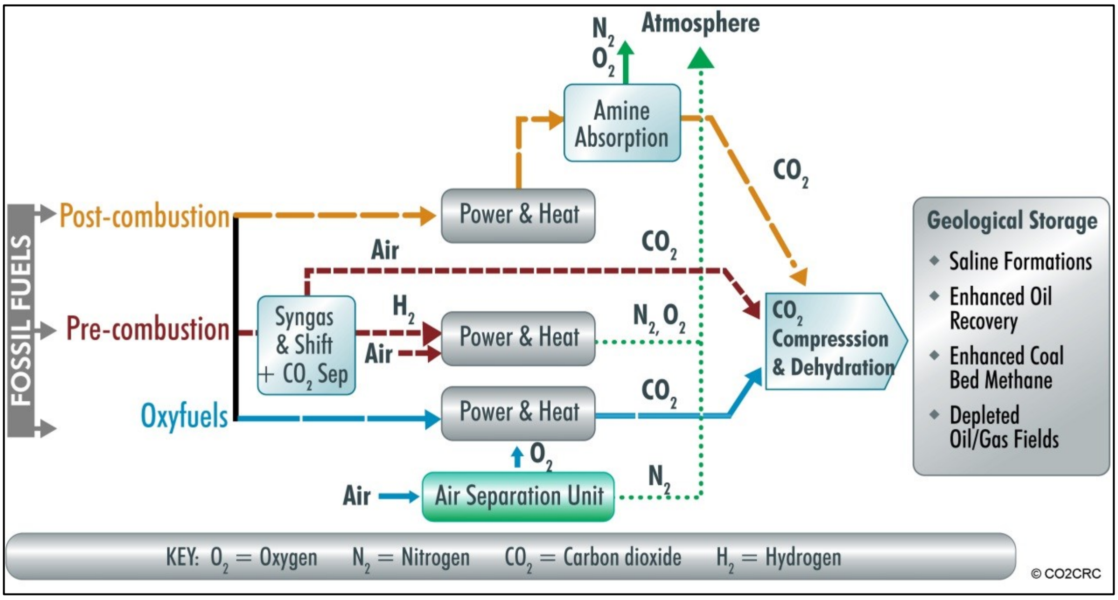

Figure 4.1: Main current technology options for CO2 capture from fossil fuel usage (source: CO2CRC (www.co2crc.com.au [2011])).

In post-combustion capture the CO_2 is removed at the final stage of the process, after the fossil fuel has been burned and just before the combustion products are vented to the atmosphere. One method involves wet scrubbing with aqueous amine solutions at relatively low temperatures (around 50°C) to remove CO_2 from the waste gas. The amine solvent then has to be regenerated for re-use by heating it to higher temperatures (approx 150°C), during which the CO_2 is removed, before the solvent is cooled and recycled. Lastly, the CO_2 captured during the regeneration process is dried, compressed and transported to a safe geological storage site (Figure 4.1). This particular approach is very energy intensive and consequently results in the high costs associated with CCS capture technologies (Gibbins & Chalmers 2008). Even though post-combustion capture is an established method, when scaled-up, it could consume 25-40% of the fuel energy of a power plant and be responsible for 70% or more of the additional costs to CCS (House et al. 2009).

Pre-combustion capture entails the removal of CO_2 prior to the combustion process, where fossil fuel or biomass can be partially combusted (e.g. gasified or reformed). Different technology options exist (e.g. gasification with oxygen and steam at high pressure), but a common feature of these options is that a gas, or 'syngas', comprised of CO and H_2 is formed (Figure 4.1). The gasification process for coal (and also the reforming process for natural gas) is an established method where the syngas can be used to power turbines or in industrial applications such as fertiliser production. When water (steam) is added to syngas, the temperature is reduced and the CO converts to CO_2[30], which can then be separated using a physical solvent (e.g. one which releases captured CO_2 when pressure is increased) to leave a hydrogen-rich fuel gas (USDOE 2006). Given that no heat is required to regenerate the solvent in this process, the direct energy requirement in pre-combustion capture technology may be half of what will be required for post-combustion capture. However, there are additional efficiency penalties associated with the pre-combustion capture system. This is because hydrogen-burning gas turbines have a lower efficiency than conventional natural gas or syngas units, mainly due to higher heat-transfer coefficients for combustion products from hydrogen-rich fuels (Gibbins & Chalmers 2008).

Oxyfuel combustion involves burning the fossil fuel in an oxygen-rich environment (approx 95%) rather than air, where the main separation step is oxygen from nitrogen, as shown in Figure 4.1. This process produces a flue gas that is largely comprised of CO_2 and condensable water vapour. In this case, any components in the flue gas that are not CO_2 can be separated relatively easily during the CO_2 compression process. In the case of coal, oxides of nitrogen and sulphur (NO_x and SO_x), plus other pollutants will all need to be removed from the product gas before or during the CO_2 compression process (USDOE 2008a).

When comparing the capture technologies in terms of application to power generation using fossil fuels, a study by the IEAGHG in 2006 indicated that higher capital costs are associated with coal-fired power generation, rather than gas-fired, where post-combustion capture on gas is the least expensive option with the highest thermal efficiency. In addition, post-combustion capture on coal using best current commercial technologies are predicted to have higher thermal efficiencies for conversion to electricity than pre-combustion integrated gasifier combined cycle

[30] This process is the 'water-gas shift' reaction; where the mixture of the synthesis gas and steam is passed through a series of catalyst beds for the water-gas shift reaction to approach equilibrium: $CO+H_2O \Leftrightarrow CO_2+H_2$ (USDOE 2006).

(IGCC) designs, and is the least expensive option out of the three technologies for coal (IEAGHG 2006). There is, however, substantial uncertainty associated with the costs reported by this study (and others completed with technologies at this stage of development). More recent analysis by Mott MacDonald (see UKERC 2012, p. 7) also indicates that the total capital costs associated with CO_2 capture at gas-fired power plants are the lowest in comparison with the other coal-based power plant technologies that were assessed. In terms of efficiency, Mott MacDonald's report found that the energy penalty is roughly ten percentage points when CO_2 capture is included on a coal power plant, meaning that the plant's efficiency would be lowered from 42% to 32% (UKERC 2012, p7). Therefore, CCS is not without costs, and its role as a solution to climate change is not straightforward.

4.2.2 Transport

The majority of studies assume that once captured, the CO_2 is pressurised to around 110 bar to 150 bar, reducing its volume and forming a supercritical fluid (with density that is liquid-like, but viscosity that is gas-like) that can be transported away from the source to the storage site via dedicated pipeline infrastructure. Transporting liquefied CO_2 by ship is also possible. Pipelines are generally feasible when the distance between the source of emissions and storage sites is in close proximity (GCCSI 2011). Again, the transport of CO_2 using pipelines is not a novel concept, and it is an established technology both on land and under the sea. At present, approximately 50Mtpa[31] of CO_2 is transported in 6,000km of pipelines in North America, where the majority of this network lies in the US and has been developed over the past 40 years (*Ibid.*). This pipeline network supports the US oil and gas industry, where CO_2 is transported and used to augment oil production (see following section for more detail). The USDOE is currently considering how this existing network can also be used or adapted to support potential CCS projects (*Ibid.*). Therefore, similar to CO_2 capture, transport technology using pipelines was designed for a different purpose, and is essentially a part of an established sociotechnical system, i.e. fossil-fuel production.

[31] Million tonnes per annum

However, there are still some technical issues that need to be considered, chiefly the corrosive properties of supercritical CO_2 and its impact on the durability of the steel pipes, as well as the purity of the CO_2 stream captured that is to be transported in order to meet health and safety standards (IPCC 2005). Other factors that can influence CO_2 transport through pipelines are geographical location, terrain, and territorial boundaries. Still, pipelines are advantageous for large quantities and relatively short distances, provided that a steady state flow is received (Svensson et al. 2004), i.e. a continuous flow from the point source to the final storage site, thereby allowing for a possible elimination of buffer storage (see Figure 4.2). This implies that the requirement of steady flow may not suit the intermittency associated with some capture and injection technology, and therefore shipping would be more appropriate.

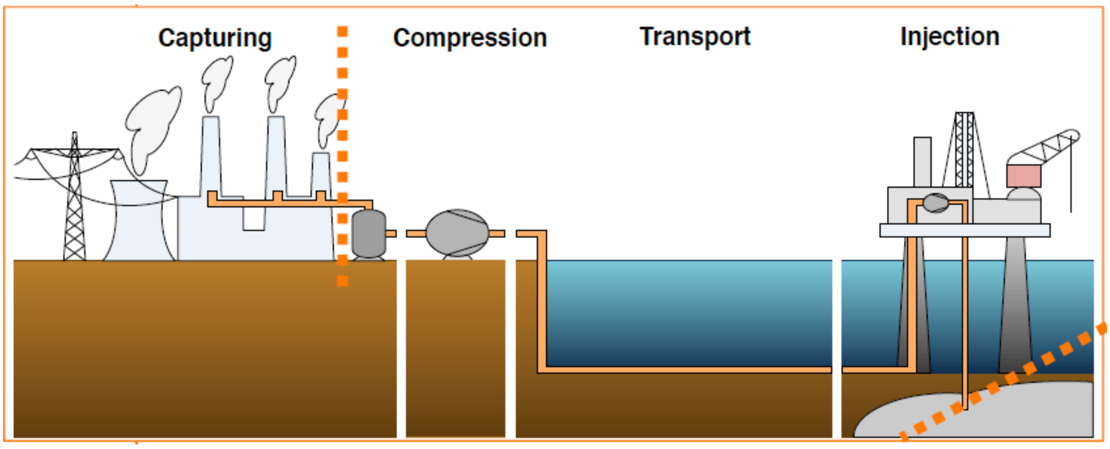

Figure 4.2: CO2 transportation using pipeline infrastructure going to an offshore injection site (source: Anthony Veder (www.anthonyveder.com [2011])).

In cases where the large point source of CO_2 is not in close proximity to suitable storage sites, a more flexible and cost-effective way to transport the CO_2 emissions could be via shipping vessels. This is particularly relevant for India as suitable storage is limited and predominantly offshore (see Chapter 7). Shipping CO_2 is already a viable technology, though only on a kilo-tonne scale (IEAGHG 2004). A marine transportation system essentially consists of a CO_2 liquefaction system, intermediate storage and loading facilities, CO_2 transporting ship, and receiving facilities (see Figure 4.3). As with pipelines, gaseous CO_2 is fairly inconvenient cargo for shipping, because its volume at atmospheric pressure is too large for its weight. Therefore, the liquefaction process is essential prior to shipping in order to reduce the volume. CO_2 transportation by ship has a number of similarities to the current transportation of Liquefied Petroleum Gas (LPG) and Liquefied Natural Gas (LNG). Consequently, for the design of the ship, tank form and onshore loading system, the existing technology for LPG transport has been the starting point for the development of CO_2 transport (Aspelund et al. 2006).

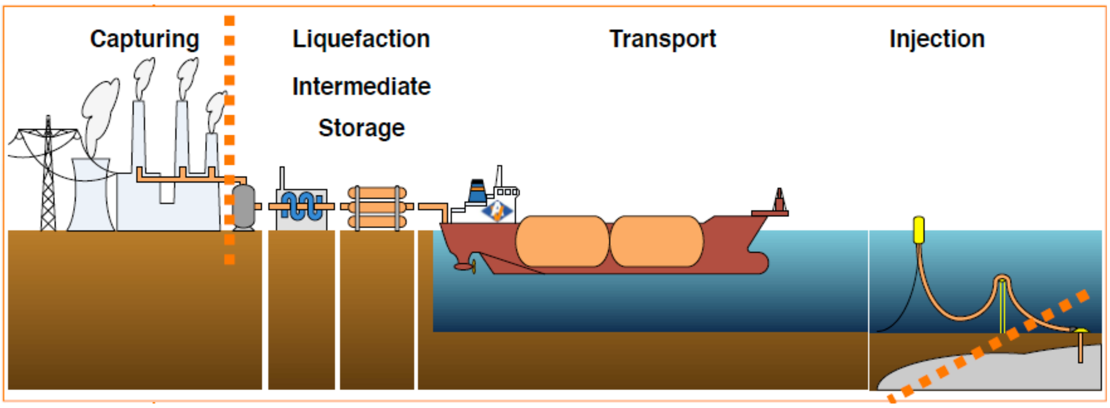

Figure 4.3: Main processes in the marine transport system (source: Anthony Veder (www.anthonyveder.com [2011])).

Studies by the IEAGHG (2004) and Aspelund et al. (2006) describe the processes of the chain illustrated in Figure 4.3 in detail. As noted above, once the CO_2 has been captured, it needs to be liquefied and stored at an intermediate storage facility. A typical liquefaction plant is expected to deliver CO_2 at 6.5 bar and -52°C to the intermediate storage tanks. If an onshore CO_2 hub were to be introduced, intermediate storage facilities matching the incoming amounts of liquefied CO_2 from a range of CO_2 sources would be needed. The CO_2 is stored at the bubble point[32] in semi-pressurised storage tanks until the ship berths at the quay. The loading system at the quay transfers the liquefied CO_2 from these storage tanks at the liquefaction plant to the ship. The system includes all the necessary piping between tanks and ship, as well as pumps, and infrastructure for marine loading and offloading (Aspelund et al. 2006). Usually two parallel product pipes are provided between the tanks and the loading mechanism for discharging CO_2 and a return line for CO_2 vapour generated at the ship.

[32] The bubble point is when a liquid forms the first bubble of vapour as it begins to evaporate.

The offshore unloading system will unload the ship using an appropriate system given the location of the planned CO_2 storage. The availability of the unloading system is of high importance to ensure a cost effective transport chain. Furthermore, a rapid unloading rate is important to increase the ship utilisation and reduce the total transport costs (Aspelund et al. 2006).

Finally, the capacity, service speed, number of ships and shipping schedule that is planned will have to take into account the capture rate and injection rate of CO_2, transport distance, and any social and technical restrictions (IEAGHG 2004).

4.2.3 Storage

The last stage of CCS is the most critical for the purpose of climate change mitigation. Given the amount of CO_2 produced and captured at point sources, mitigation efforts require the permanent storage of the CO_2 in deep underground geological formations. These formations that are expected to be most relevant for CCS have the natural trapping mechanisms that have led to the formation of oil and gas fields and that are also expected to be able to retain CO_2 for millennia; and so they are considered to have the capacity to accommodate large volumes of CO_2 for tens of thousands of years. Storage of CO_2 is achieved by injecting CO_2 at depths of around 800m or more below the surface, where at that depth and pressure it will be a supercritical fluid[33] (which is different from the fluid state that it is transported in), and seeps into the microscopic pore spaces of sedimentary basins[34] (Holloway 2001). Sites considered suitable for storage include depleted oil and gas fields, unmineable coal-seams, or deep saline formations (see Figure 4.4). Other options are also being explored, such as the potential of CO_2 storage in flood basalts[35], which may be of significance to India. This

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[33] CO_2 turns into a liquid state or becomes 'supercritical' when both its temperature and pressure go above their critical points, which is 31.1˚C and 7.39MPa respectively.

[34] Basins in this context are structural formation of rock strata, depressions, and usually of considerable size.

[35] Continental flood basalts are the result of huge volcanic eruptions, which coated vast areas of land with basalt lava in volumes of thousands of cubic kilometers (Hancock et al. 2000). Flood basalt areas are also referred to as 'traps'; the Deccan Traps in India extend for hundreds of kilometers (*Ibid.*).

option is further explored in Chapter Seven, which covers specifically India's geology and storage potential.

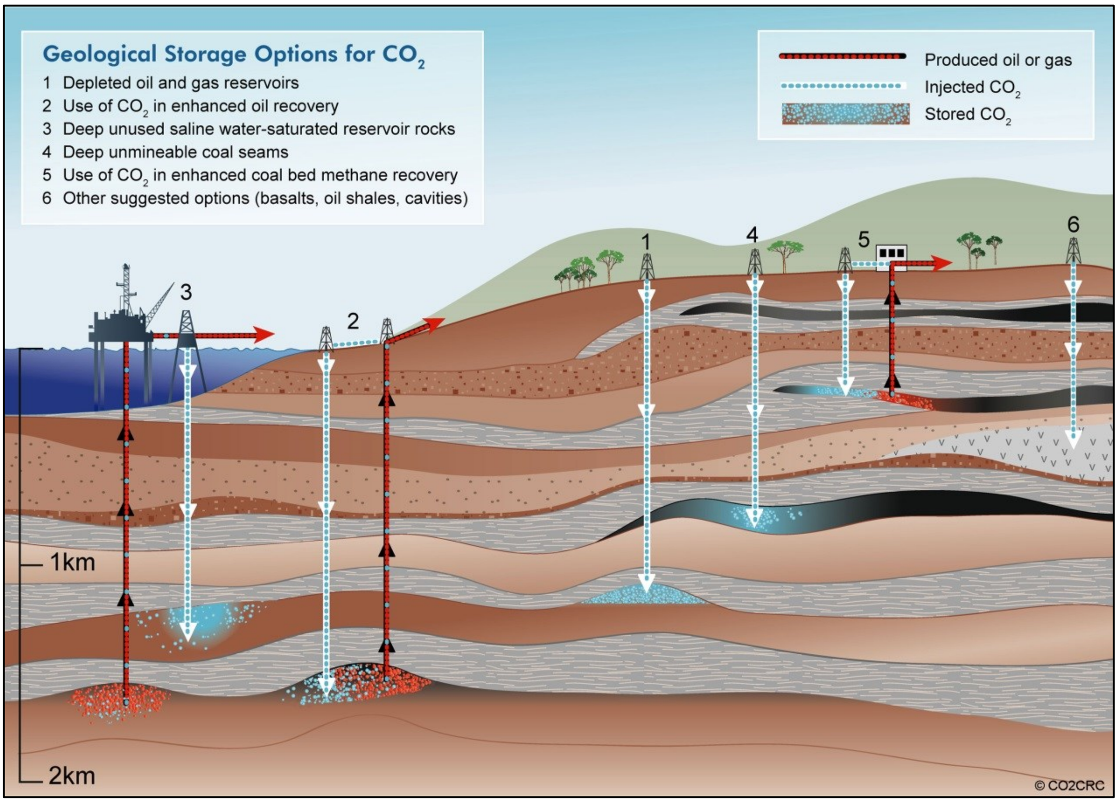

Figure 4.4: Different options for geological storage of CO2 (source: CO2CRC (www.co2crc.com.au [2011])).

The concept of CO_2 storage is based upon the experiences of the hydrocarbon industry, which have been injecting CO_2 into the deep subsurface since the 1970s for a practice known as enhanced oil recovery (EOR). Generally, hydrocarbon fields consist of a layer of porous rock containing liquid oil and gas, which is sealed by an impermeable rock-layer, or a 'caprock' above the reservoir. The oil or gas is extracted from the deep subsurface through drilling boreholes through the caprock. This subsequently decreases the pressure within the reservoir rock, and it can be increased back to original pressures by injecting additional water (referred to as 'brine' in this context) from the surface. In some cases however, naturally occurring CO_2 has been co-injected with brine because it can chemically dissolve into the oil, decreasing the viscosity of the fluid, which then flows more easily to the surface (see Figure 4.5).

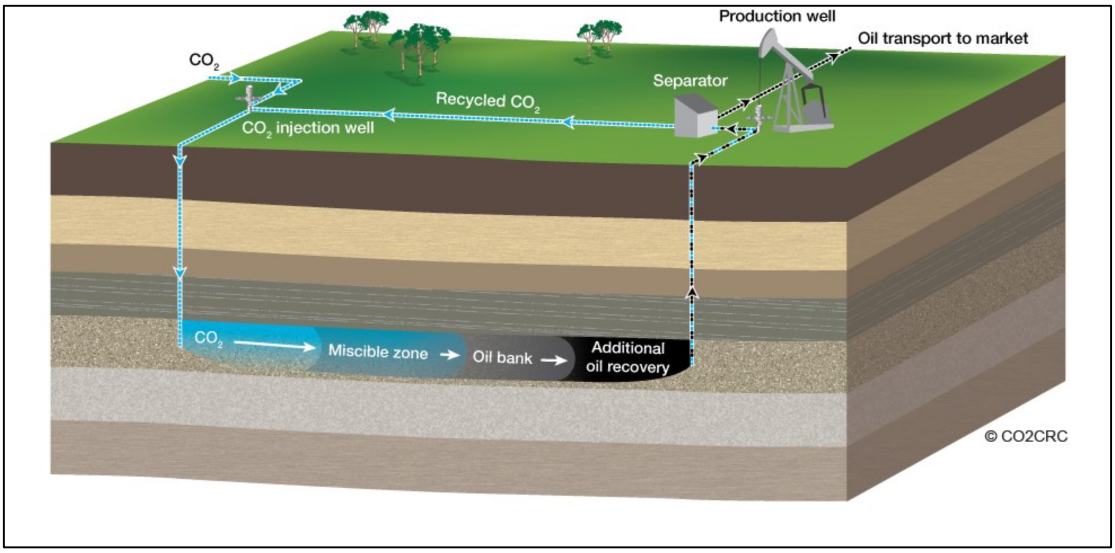

Figure 4.5: Enhanced Oil Recovery (EOR) with CO2 injection (source: CO2CRC (www.co2crc.com.au [2011])).

The caprock and subsequently other geological features trap the CO_2 and prevent it from returning to the surface. Pre-existing boreholes that have already punctured the natural seal of the caprock would, however, need to be monitored as potential leakage pathways (Haszeldine 2009). Depleted oil and gas fields tend to be the preferred option for CO_2 storage because they are well characterised, including the understanding of the three-dimensional geometry of rock structures, which is derived during the exploration and production of hydrocarbons (Haszeldine 2011). With EOR, CO_2 injection technology is demonstrated and developed at a transferable scale, requiring similar mechanical and fluid engineering that is currently used by industry to circulate such large volumes of fluid on a daily basis (USDOE 2008b). For example, presently the US handles roughly 16 million bbl[36]/day of fluid hydrocarbons and 38 million bbl/day of water injection on a routine daily basis (Haszeldine 2011). This opens up the potential for the existing infrastructure to be recycled, which is likely to be cost effective. Additionally, some aspects of these mature technologies have already been transferred

[36] bbl is a unit of measure used in the hydrocarbon industry for barrel of oil, where 1 barrel (bbl) = 42 US gallons

to or used in other countries via multinational oil companies. Again, this prior use and existing infrastructure is important in understanding the commercial and political appeal of CCS technology. Notably, this existing infrastructure has a dual nature, as in some respects it can encourage uptake of CCS, e.g. low investment risk due to established injection technology know-how; but it can also be a hindrance, e.g. the extra cost for an entirely new large-scale pipeline networks required solely for CO_2 transportation.

Coal beds are considered as good sites for potential CO_2 storage due to their substantial capacity of coals to store gases by adsorption on their surfaces and within their porous structures. Whilst coal is underground it is coated with a layer of methane (CH_4), and coal-beds generally can be a major source of natural gas. Since the 1970s CO_2 has been considered as an effective means to remove methane from coal in a process known as Enhanced Coal Bed Methane (ECBM) recovery (White et al. 2005). Similar to the EOR concept, ECBM involves injecting CO_2 or a mixture of gases into a coal seam, where the CH_4 is displaced when CO_2 adsorbs onto the coal in its place. ECBM is most useful in unmineable coal seams, which are defined as deep underground coal for which mining is economically unfeasible, usually constrained by costs, sale prices and available technology (USDOE 2008c). This can be due to the natural conditions of the seam, where the coal is at an excessive depth. Additionally, this storage option is not receiving that much attention in many places due to relatively limited expected overall capacities for storage (GCCSI 2011).

CO_2 injection into deep saline formations is not as well explored or demonstrated, and is consequently far more challenging. However, they do offer a potentially enormous capacity for CO_2 storage, more so than hydrocarbon fields, where potentially they could store decades or hundreds of years' worth of CO_2 emissions (Holloway 2001; IPCC 2005). Deep saline formations (or aquifers) are porous rocks filled with very salty water, which makes them unsuitable for providing water for drinking or agricultural practices, and are also more commonly found offshore. Out of all the CO_2 storage options, this is one of the most significant in terms of capacity and potential, however less is known about deep saline formations compared to oil and gas fields. Nonetheless, a number of pilot projects and existing commercial operations have been demonstrating CO_2 injection into deep saline formations for a number of years. A review of the experience gained from such projects by Michael et al (2010) concluded that CO_2 storage in deep saline formations is technically feasible, but further demonstration at a much wider scale with fully integrated CCS projects is needed. Moreover, deep saline aquifers are more prevalent globally, and even though India is limited in storage in terms of its hydrocarbon fields, this geological option may have potential, particularly in the future, if CO_2 emissions were to be shipped elsewhere.

The following section considers the complexities and challenges associated with presenting CCS as a coherent and integrated technology, given its mixed history of quite separate functions, using an STS approach. This leads to a discussion on the political dimensions and underlying commercial objectives of CCS technology, which adds to its mixed identity.

4.3 CCS: is it a coherent system or just a political project?

Capturing CO_2 and storing it permanently for climate change mitigation and emissions abatement can be considered a radical *idea* or *vision*. However, as highlighted in the previous section, the three parts of the CCS chain, i.e. capture, transport and storage, build upon existing technologies, which were designed for a different purpose entirely (i.e. the driver was not climate change mitigation). There are presently very few projects that are at scale, and technically integrate all the parts of the CCS technology system from capture through to permanent storage. Therefore, it can be argued that each of these stages are individually established technologies, and in essence are a collection of incremental technological innovations. Based on the technology conceptualisation diagram presented in Chapter 2 (see Figure 2.1), they can be visualised as separate entities, each with its own culture, regulations, institutions, market etc. (see Figure 4.6). In this way, it is misleading to describe CCS as a technology; it is actually more like a system, comprising multiple technologies, objectives and types of expertise.

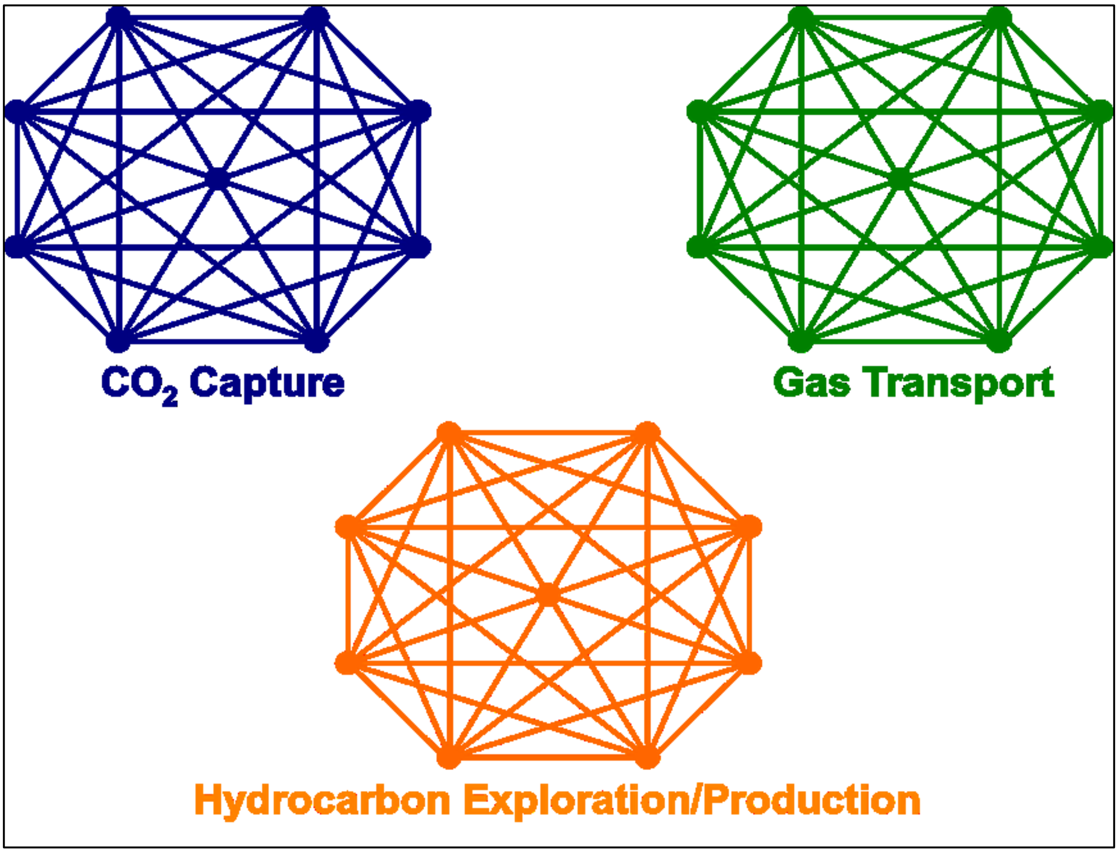

Figure 4.6: STS concept diagrams of the existing technologies that contribute to the CCS technology chain.

Across the CCS chain, within the three different stages there is flexibility with a variety of options, allowing CCS to be adapted to different conditions. There is currently no optimum combination between these technology options, and variations in site-specific factors are likely to determine which suite of technologies will be best for a particular purpose. However, this advantage of flexibility can also be a weakness, adding more complexity to the system, which in turn becomes more challenging to define boundaries and present a coherent system. Based on the previous figure, CCS technology is presented as a schematic diagram in Figure 4.7, illustrating the complexity associated with creating a coherent system. This coherence is an important issue, for example, for the UK Government, which was trying to present CCS as a viable climate mitigation tool to India and other developing countries. The configuration of CCS below is just a visual example, and this can change depending on which combination of technology options are used. It may be that more aspects of the different stages could be incorporated into the CCS chain, therefore making the red circle in Figure 4.7 bigger. Also, over time these boundaries may change, as specialist areas emerge and the need to borrow directly from existing fields could diminish, therefore reducing the size of the red circle. Therefore these boundaries of a CCS system are changeable, contributing further to its flexible nature.

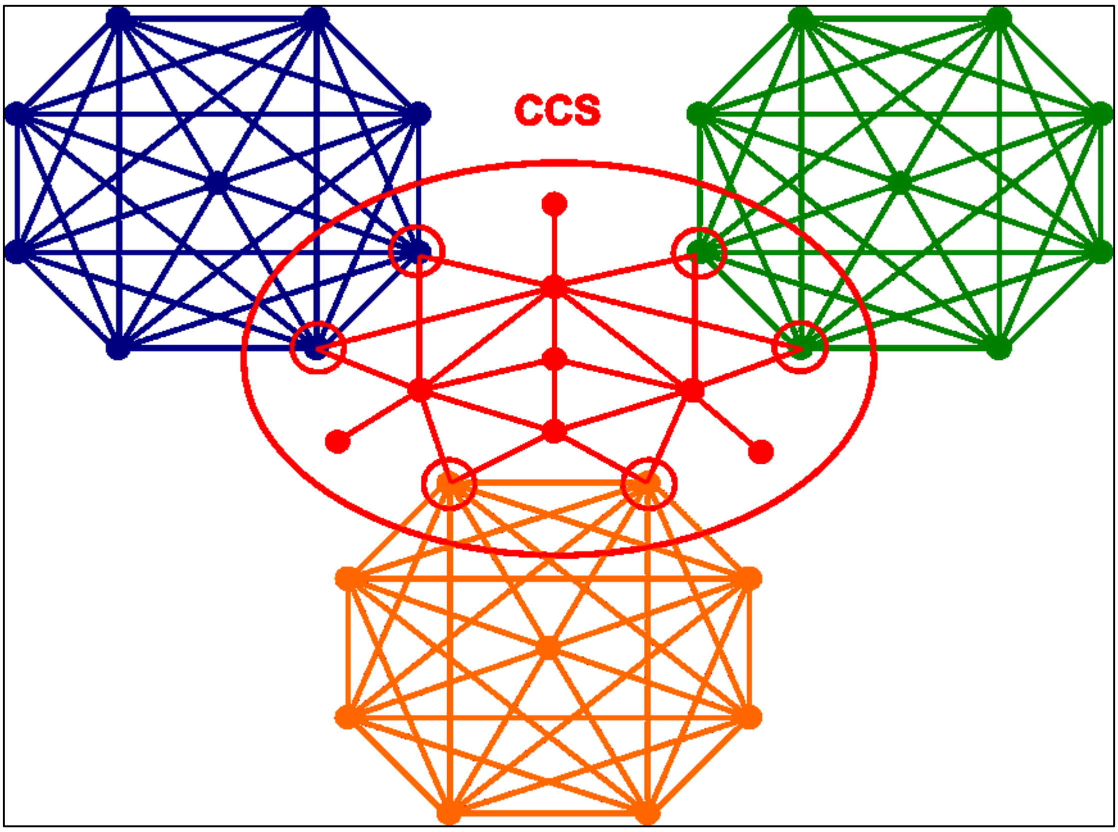

Figure 4.7: An example of a STS concept diagram for a CCS technology chain.

Moreover, the previous section also highlights the need to tweak, or adjust, the existing technologies specifically for CCS purposes. These could be considered as incremental innovations. However, their purpose is not to enhance the existing technology, rather, they are incremental innovations for a radical vision. Furthermore, the motivation behind such innovations does not necessarily match the ethos of the established technologies in Figure 4.6. For example, the hydrocarbon industry historically is based upon the *extraction* of resources from geological formations, rather than trying to *contain* a substance *permanently* within the strata (see Haszeldine 2011). Similarly, there is an energy penalty associated with the process of CO_2 capture, reducing power available for export from a power plant, and therefore bringing down the overall efficiency of a power plant if it is using a CO_2 capture facility. Therefore, a different philosophy is needed for CCS, though how does one achieve that, when there are different cultures already imbedded within the technologies required to make it work? This is a fundamental issue when it comes to defining CCS, contributing to its mixed identity. In essence, CCS technology calls for a technological revolution (see discussion in Chapter 2). This is not based on a cluster of radical innovations, but rather a cluster of incremental innovations from other combined systems in order to have a long-term impact on society. Again, this description indicates a mixture of identities, and therefore CCS challenges the theories discussed in Chapter Two, which set out the boundaries of technology and innovation as much more discrete and simple. As a result, it is difficult to define CCS as a coherent technology that can be transferred to other countries: it is more akin to a sociotechnical system.

This changing identity of CCS makes it difficult to develop and transfer internationally. Notably, the representative from the Indian Ministry of Science and Technology opined that CCS didn't come across as very "innovative" or "cutting-edge" compared to nuclear[37] technology, stating that CCS seemed to be "old kit being dressed up and sold as something new," and rather felt like "a step backwards" (Interview A1, 2008). Another interviewee, from India's National Thermal Power Corporation Ltd, (NTPC) thought the CCS vision would be considered more 'novel' and have greater appeal to India if the CO_2 could somehow be converted into material for use, e.g. as feedstock for cement production; injecting CO_2 underground seemed like a waste (Interview B9, 2008). Therefore, the CCS vision at this stage was still open to interpretation due to its mixed identity, and its role in mitigating climate change was not fully embraced in India.

In addition, like many technologies, CCS transcends sectors and can also cross geographical boundaries. Current research is being driven by commercial Multinational Corporations (MNCs) and Governments of those countries that have a historical

[37] There was a consistent comparison made between nuclear and CCS technology by interviewees and stakeholders that participated in the survey. This comparison and its relevance to India's energy sector is presented in greater detail in Chapter Five.

aptitude with exploiting hydrocarbons and have very advanced industrial sectors, adding very a strong political dimension to the CCS system. This dimension is best viewed through a technological political realist lens, where the state has a significant role, and is a rational actor motivated by self-interest. The aim is "to gain influence among political elites and to secure markets for their goods" via technology transfer (Josephson 2006, p. 151). One way to achieve this would be to claim that CCS is a proven technology or viable concept as indeed was attempted by the UK and others in India during the study period. These political aspects of CCS are discussed more detail in the following section.

CCS is being actively developed in Europe, North America and Australia, and according to the Australian-based Global CCS Institute's (GCCSI) most recent report, there are eight large-scale projects currently in operation with a further six in construction (GCCSI 2011). These fourteen projects are listed in Table 4.2, where it is estimated that their combined storage capacity would total at over 33Mt of CO_2 annually (*Ibid.*). To put it in the context of mitigation, the GCCSI describes this number to be the equivalent of "preventing the emissions from more than six million cars from entering the atmosphere each year" (*Ibid.*, p. 10). It should be noted that an EOR-based project cannot be considered a 'full' CCS project, or mitigation option, without monitoring, measurement and verification (MMV). Therefore, some of the older projects listed in the table below exhibit the initial capture, transport and injection aspects of CCS, but would require "further MMV systems and processes to be consistent with the demonstration of permanent storage" (*Ibid.*, p. 12). Nevertheless, the GCCSI report includes such projects as a means for supporting the vision that CCS is a proven concept.

Table 4.2: Current Large-Scale Integrated CCS Projects (operational/ in construction); table adapted from GCCSI (2011).

Location	***Project Name***	***Status***	***Industry/ Capture Technology***	***Storage Type***	***CO2 Injected (Mtpa)***	***Year of Operation***
Algeria	In Salah CO2 storage	Operational	Gas processing/ Pre-combustion	Deep Saline Formation	1	2004
Australia	Gorgon CO2 injection	In construction	Gas processing/ Pre-combustion	Deep Saline Formation	3 - 4	2015
Canada	Boundary Dam with CCS	In construction	Power/ Post-combustion	EOR	1	2014
Canada	Agrium CO2 Capture with ACTL	In construction	Fertiliser/ Pre-combustion	EOR	0.6	2014
Norway	Sleipner CO2 injection	Operational	Gas processing/ Pre-combustion	Deep Saline Formation	1	1996
Norway	Snøhvit CO2 injection	Operational	Gas processing/ Pre-combustion	Deep Saline Formation	0.7	2008
USA	Val Verde Natural Gas Plants	Operational	Gas processing/ Pre-combustion	EOR	1.3	1972
USA	Enid Fertilizer Plant	Operational	Fertiliser/ Pre-combustion	EOR	0.7	1982

Location	***Project Name***	***Status***	***Industry/ Capture Technology***	***Storage Type***	***CO2 Injected (Mtpa)***	***Year of Operation***
USA	Shute Creek Gas Processing Plant	Operational	Gas processing/ Pre-combustion	EOR	7	1986
USA/ Canada	Great Plains Synfuels Plant & Weyburn – Midale CO2 monitoring & storage	Operational	Synfuels production/ Pre-combustion	EOR with MMV[38]	3	2000
USA	Century Plant	Operational	Gas processing/ Pre-combustion	EOR	5	2010
USA	Lost Cabin Gas Plant	In construction	Gas processing/ Pre-combustion	EOR	1	2012
USA	Illinois Industrial CCS Project	In construction	Industrial (ethanol production)	Deep Saline Formation	1	2013
USA	Kemper County IGCC	In construction	Power/ Pre-combustion	EOR	3.5	2014

[38] The Weyburn/Midale fields have been operational carbonate oil fields since the 1950s, however, CO_2/water co-injection started in 2000 for EOR with an IEAGHG initiative to monitor the movement of the CO_2 using 4D time-lapse seismic technology (GCSSI 2011).

The committed projects listed in Table 4.2 are predominantly based on EOR and gas processing, highlighting further the dominant role of the hydrocarbon industry. Of the eight currently operational projects, none are in the power sector, largely due to issues of cost, scaling-up and improving the efficiency of the capture process. However, despite these challenges, several are now in the planning process or in construction, such as the Boundary Dam project in Canada with post-combustion capture, or the Kemper project with IGCC in the USA, indicating a shift towards developing CCS capability for electricity generation.

Nevertheless, CCS in the power sector remains a high-risk option, where the GCCSI has highlighted the lack of financial and policy support as the primary reasons why projects have been cancelled or stalled (GCCSI 2011). The IEA's recent World Energy Outlook report predicts that the cost of electricity generation can increase from nearly 40 to 65% (depending on fuel source and technology used) if CCS technology is added to power plants (IEA 2011a). The power projects noted earlier receive considerable support from the US and Canadian Governments in terms of funding for R&D. In Europe, CCS power projects that were in the planning stages have been cancelled, including the Longannet project in Scotland, largely due to financial factors (White 2014). The Vattenfall project in Jänschwalde, Germany, was cancelled primarily due to large-scale public opposition to onshore CO_2 storage, citing environmental and safety concerns, along with the rejection of the CCS Bill in Germany's Bundesrat (upper house) (Reuters 2011).

Therefore, it is important to note that CCS is a radical vision, which has yet to be widely materialised even in developed states. Consequently, India is suspicious about the prospects of CCS, where the majority of stakeholders surveyed ranked 'technology readiness' as the top challenge for both initial projects as well as for widespread development (Survey 2009, Appendix B). The general feeling amongst stakeholders was that CCS had to be technologically demonstrated in developed countries before it could be applied to India (*Ibid.*). One survey respondent was of the opinion that "the developed nations will first need to show that they are using CCS on their own grounds otherwise political acceptance of technology will be an uphill task and long winded" (Respondent 15, Survey 2009, Appendix C). Another stakeholder stated:

> *"In our reading, [CCS is] an unproven technology with unknown costs, unknown environmental implications and unknown energy implications of transportation of CO_2, hence we don't favour it."*
> *(Respondent 16, Survey 2009, Appendix C)*

There are a limited number of CCS projects in developing countries, which are, like India, largely waiting to see how the technology will develop in industrialised nations first. Other than the In Salah project in Algeria (Table 4.2), which was initiated by BP, there are a few projects planned in the UAE[39] which are centred on pre-combustion capture with EOR (Masdar 2012). China has also shown a growing interest by focusing on domestic R&D in CCS technologies, with seven projects currently in the planning stages (GCCSI 2011). However, China is not seen as an innovator, and these projects put more emphasis on *utilizing* CO_2, either for EOR or the soft-drink industry. Researchers observed that the technology used in China was nearly twenty years old, and not necessarily being used with the aim of climate mitigation (Carrington 2012). There have been a few initial feasibility studies by international organisations, such as the IEAGHG's research on the CO_2 storage potential in the Indian sub-continent (IEAGHG 2008), and the World Bank's report on deployment issues in southern African states (Kulichenko & Ereira 2011). However, there are no projects planned in these regions, and the IEA's CCS roadmap considers them unlikely to develop there until 2020 (IEA 2010).

The reoccurring issues with all the projects reviewed above is cost and policy support, highlighting the importance of the economic and political dimensions of technology development. These issues are discussed further in the following section.

4.3.1 The Political Project with a Commercial Objective

Traditionally energy policy has been based upon economic and security concerns, where energy is seen as "a foundation for economic growth, prosperity and military power" (Meadowcroft & Langhelle 2009, p.17). However, given that the motivation for CCS is climate change mitigation, then there is a need to:

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[39] United Arab Emirates

"… [position] environmental issues at the heart of energy policy, and [insist] on the need to radically restructure the energy economy in order to decouple economic activity from environmental pressures, and bring resource use and waste generation back within the supportive capacity of natural ecosystems." (Ibid.)

This implies a substantial overhaul of our current energy system, and Meadowcroft & Laghelle (2009, p. 18) point out that the contribution of CCS needs to be "judged in relation to the wider challenge of developing a carbon neutral energy system, as well to the requirement of sustainable development." Climate change is a global problem, and if CCS is to be part of this movement towards a low-carbon economy, then political support is paramount for any long-term changes to global society.

However, there can be a conflict of interests, specifically, between the traditional drivers of energy policy and environmental concerns. Economic concerns are still a very strong driver for technology development and the "costs and risks must be considered as well as promised benefits" (*Ibid.*). Therefore, the costs associated with developing CCS at scale can impede technology development. Nevertheless, this section demonstrates that there was a very strong underlying power-based interest and business case objective for developing CCS technology.

It is no coincidence that CCS R&D activities are concentrated in specific developed nations. According to the United Nations Framework Convention on Climate Change (UNFCCC), the onus is on Annex 1 nations (developed countries) to act first to combat climate change, leading the way for Annex 2 nations (developing countries), although ultimately, action by all countries will be crucial. The review in the previous section highlights the dominance of highly industrialised CO_2 emitting countries that are key hydrocarbon producers and exporters, and are strongly influenced by energy and fossil fuel industry interests. These countries are Australia, Canada, Norway, UK and the USA, all of whom have actively engaged in the UN climate change negotiations and have "shown considerable technological and policy interest in CCS" (Meadowcroft & Langhelle 2009, p. 18).

This situation can be described further using political IR theory, where the work of de Coninck & Bäckstrand (2011, p. 377) highlights that "international institutions mirror the material interests of the most powerful states", when looking at CCS politics through the realist lens. Notably, they point out the diminished role of UN agencies such as the IPCC, for international coordination on CCS, and the increased prominence of the International Energy Agency (IEA):

> *"While the IPCC initially provided governance functions, such as the supply of information and legislation on CCS in national inventories, its role decreased in 2006. The IEA has gradually replaced IPCC as the key provider of information on CCS. The IEA is attuned to the interests of industrialized countries that are dependent on fossil fuels and possess large stakes in CCS technologies. The GCCSI also provides publicly available information. However, as an advocate for CCS, its legitimacy and independence are questionable." (de Coninck & Bäckstrand 2011, p. 377)*

The observation above is of particular significance to this specific chapter, as well as the overall thesis. It should be noted that the technical references for this chapter rely heavily upon IEA, IEAGHG, GCCSI reports, as well as government reports from the UK and the US. This coincides with the developments in CCS's R&D history, depicted in Table 4.1 (Section 4.2) and the fact that the focus of this study is on the period after 2006. Furthermore, this development illustrates the shift of political influence away from the UN, and dispersed over various international organisations, where "no single organisation can be held responsible" (*Ibid.*). This is explained further in terms of technology politics with a realist perspective:

> *"CCS only advantages governments with strong fossil fuel interests **if** climate mitigation is pursued. The primary interest of such states as Canada, Australia and the United States is not to deploy and roll out CCS, but to delay aggressive climate abatement policies while symbolically promoting CCS research and capacity building." (de Coninck & Bäckstrand 2011, p. 377)*[40]

This analysis is made in light of the initial international efforts made regarding CCS, which are listed in Table 4.1. Additionally, de Coninck & Bäckstrand (2011, p. 377) argue that after the 2005 IPCC Special Report, "the UN no longer acts as a node in the international coordination of CCS; political influence is diffused over a large group of international organisations, [where] no single organisation can be held responsible." Since that time, there is still no fully functioning and integrated CCS technological chain being realized in any of the countries listed in the above quote. Subsequently, the researchers conclude "a fragmented regime complex on CCS without substantial and regulatory commitments to CCS suits the national interests of such states" (*Ibid.*).

In addition to such political dimensions, there was also a strong business imperative for developing CCS technologies, and this objective is important to consider not only for technology transfer purposes, but in regards to the identity of CCS as well. The remainder of this section looks at how CCS development unfolded in the UK in particular, where the key advocates of CCS technology transfer were keen to highlight the potential application of CCS in emerging economies such as India and China.

In February 2003 the UK's Department of Trade & Industry (DTI) released an Energy White Paper presenting the need for urgent global action to combat climate change, and aimed to set the UK on a path to cut its CO_2 emission by 60% by 2050 (UK DTI 2003a). Notably, the White Paper also acknowledged that fossil fuels had a role to play in a low-carbon economy and recognized that coal-fired generation was still a key part of the energy mix, both in the UK and internationally, provided that its CO_2 emissions could be reduced. Furthermore, the document declared the Government's longer-term strategy of developing cleaner coal technologies as well as CCS (UK DTI 2003, p. 12). At the same time, the DTI was already reviewing the potential of CCS in

[40] Emphasis is part of the original text.

the UK, releasing a report later in the same year, which explored the technical feasibility of CCS in the UK (UK DTI 2003b). CCS was presented as a three-step process that entails the capturing of CO_2 from power plants or industrial process, then compressing and transporting the gas, which is then injected into the subsurface for permanent storage.

From the onset, the UK Government saw CCS development as of strategic importance in terms of security of supply by keeping fossil fuels central to the energy mix, but also as a mechanism for cutting CO_2 emissions in order to meet the 60% reduction target (UK DTI 2003a). However, another key element of UK energy policy was to develop cleaner fossil fuel technologies in order to give UK a competitive edge:

> *"By making our intentions clear we aim to provide the signals needed for firms to invest – and to help British manufacturers to be ahead of the game in developing the green technologies that we expect to play a large part in the world's future prosperity." (UK DTI 2003a, p. 13)*

Furthermore, the 2003 White Paper also stressed the importance of technological innovation in order to develop these technologies for the potential of international technology transfer, particularly to the developing world:

> *"… we will work both through our own national programmes and through a range of international collaborations and multilateral programmes which will* ***enable us to maximise the return*** *on our participation. We will work actively with* ***partners in the G8 and the EU*** *to develop climate change technologies which will be of benefit not only in helping us meet our own carbon reduction ambitions but also in helping others, especially in the developing world, to meet theirs." (UK DTI 2003a, p. 16)*[41]

There are two key things to note from the quote above, first the phrase "maximise the return" implies a commercial interest or a business case. Second, there is a call to collaborate with the G8 and the EU – developed nations – in order to develop

[41] Emphasis added.

technologies potentially of use to developing countries. Not only does this last point highlight the importance of international relations to achieve such collaborations, but also it indicates where the main *location* of innovation and R&D is to take place, i.e. within developed countries. The aim here was to present CCS a coherent 'product', so that it could be transferred to the developing world in the future (see discussion at the beginning of Section 4.3).

Subsequently, as part of its Cleaner Fossil Fuel Programme, the DTI released a series of reviews, firstly on CCS (UK DTI 2003b), then on CO_2-based EOR (UK DTI 2004), culminating in its Carbon Abatement Technologies (CAT) Strategy (UK DTI 2005), which presented a suite of technologies for cleaner fossil-fuel use, which included CCS with the potential to reduce CO_2 emissions by 85%. The CAT strategy was developed to signal the Government's support for the commercial development and deployment of these technologies for both UK and global markets, and CATs were presented as complementing renewables, as part of the "family of sustainable energy technologies for tackling climate change" (UK DTI 2005, p. i).

These developments have a significant bearing on the identity of CCS. Notably, CCS was described as "the most *radical* of the CAT options" that "involves the deployment of a *chain* of technologies for CO_2 capture, transportation and storage," rather than just focusing on the combustion process alone (UK DTI 2005, p. 5)[42]. It seems that CCS was being presented as something revolutionary, which would have a major impact on society globally. However, Section 4.2, as well as the discussion at the beginning of Section 4.3, shows that the capture, transport and storage parts of the CCS chain are all mature and established technologies in their own right. Moreover, the technologies of each of the stages are mature only in their application contexts, and will therefore require further development for use in the new application of CCS. Therefore, the 'radicalness' of this vision is more to do with linking plus adapting all of these components together and at a far more significant scale, as well as introducing a new

[42] Emphasis added.

policy objective of CCS – climate mitigation. These new additions bring complexity to the CCS sociotechnical system, its development, and subsequently its transfer.

Moreover, the UK CAT strategy had specific developing countries in sight for potential technology transfer, highlighting that by 2030 China and India would likely account for nearly half of the energy demand (and subsequent emissions) of the total developing country demand (UK DTI 2005, p. 4). In fact, there is an entire section dedicated to engagement activities with China and India within a special report of the House of Commons Science and Technology Committee (UK House of Commons 2006, p. 32). Therefore, it can be shown that from the beginning CCS was being developed as a coherent package to be exported, targeting emerging economies with increasing energy demand in particular. This ambition reflects the overall approach of UK foreign policy at that time, which was to combine China and India together and view them as a single entity. The twinning of these two countries in the context of CCS was best demonstrated at the 2005 G8 Gleneagles summit, and later within the Stern Report in 2006 (see section 1.1). As Chapter One demonstrates, however, this linking of China and India was based on a fundamental misunderstanding of the Indian social and political context.

Interestingly, in the House of Commons report it was noted by Brian Morris, the head of the DTI CAT strategy at the time, "China had responded far more positively than India to the UK's approaches regarding CCS" (UK House of Commons 2006, p. 32, Paragraph 68). Furthermore, it was noted that "the major obstacle to the adoption of CCS technologies by countries such as India and China is still the lack of value attached to carbon internationally" (*Ibid*., p. 33, Paragraph 70). This highlights the importance of an economic incentive in order to encourage adoption of the technology, e.g. additional revenues from EOR, which is why it is the dominant storage option in proposed projects (see Table 4.2). Notably, a survey respondent commented, "from the Indian point of view CCS has very limited application unless this technology is packaged with Enhanced Oil and Gas Recovery options" (Respondent 1, Survey 2009, Appendix C).

In the context of technology transfer, the exporting opportunities were also considered by the UK Government, stating that "opportunities for UK companies are likely to derive from intellectual property and licensing of CCS technology", where the

UK is more likely "to sell the knowledge" because it is expected that "China and India would build their own equipment very quickly" (UK House of Commons 2006, p. 35, Paragraph 74). The discourse alludes to CCS as a fully-formed product, which could be easily sold abroad, however in reality a full scale CCS demonstration project was yet to be developed and constructed in the UK at the time the House of Commons commissioned the report.

Subsequently, CCS became an important feature of the UK Government's position in the run up to the December 2009 UNFCCC negotiations in Copenhagen. In June 2009, the UK Department of Energy and Climate Change (DECC) released a report stating its strategic ambitions regarding CCS and its role within the negotiations:

> *"In October [2009] the UK will be co-hosting with Norway the Carbon Sequestration[43] Leadership Forum (CSLF) where we aim to scale up international action on Carbon Capture and Storage demonstration and build the momentum for an ambitious outcome at Copenhagen." (UK DECC 2009a, p. 49)*

The report emphasised the importance of international collaboration in the development of new technologies, particularly to "identify innovation gaps" and encourage cooperation between developed and developing countries, plus the private sector "where appropriate to accelerate development and demonstration of specific technologies" (*Ibid.*). Notably, there was a spotlight on the EU-China Near Zero Emissions Coal (NZEC) initiative, to which the UK government provided nearly £3.5 million (UK DECC 2009a, p. 50). The aim of the NZEC initiative, which was launched in 2007 (Phase I), was to assess the CCS options in China, and the Phase 1 conclusions were launched in Beijing, a month prior to the Copenhagen negotiations (*Ibid*.). In addition, DECC also stressed the need for UK-India collaboration, specifically on intellectual property rights (IPR) related barriers to the transfer of low carbon energy technologies (UK DECC 2009a, p. 47). These particular aspects of the DECC report indicate not only the strategic importance of India and China for technology transfer

[43] Technique for the long-term storage of carbon dioxide or other forms of carbon (footnote is part of the original quote).

purposes, but also demonstrate the UK Government's international political agenda to raise the profile of CCS technology as a viable climate mitigation tool.

The fact that India was so strongly against CCS at this time is interesting, particularly as this was a period when the popularity of CCS technologies was on the rise globally. Moreover, CCS was being lauded as an option for climate change mitigation that allowed the continued use of fossil fuels – something that emerging economies are heavily reliant upon. In comparison, China was already actively engaged with the NZEC programme, which was led by the UK, looking at options for CCS demonstration on coal in China (UK House of Commons 2007). Interestingly, the memorandum from BERR to the Select Committee on Science & Technology stated that the UK "is actively pursuing a similar project in India" (*Ibid.*). Essentially, at the start of the study period (2007), I was part of a key academic team that was aligned with the UK Government's ambitions. However, the reality on the ground was far different from what was anticipated. Therefore the focus of this study shifted towards the political and social aspects of India's refusal to consider CCS, (and the UK and EU's persistence in India).

4.4 Conclusion

CCS technology is complicated. It comprises of the linkage of three stages: capture, transport and storage of CO_2 emissions, all of which are based on existing technologies with varying application contexts. This gives CCS a mixed identity, making it difficult to define in sociotechnical terms, primarily because it does not fit within the traditional boundaries of technology innovation theories, as it is not a discrete technology unlike most of the empirical case studies. CCS is best viewed as a sociotechnical system, rather than a technology. Given that its raison d'être is climate mitigation, CCS could be part of a technological revolution, transforming the wider energy sociotechnical system and thereby global society, by contributing to the transition to a low carbon economy. However, in reality, CCS is a cluster of incremental innovations, combined discursively in order to create a radical vision. The 'radical' aspect of CCS is the linking and integration of the three incremental innovations, though this has not been materially realised. CCS is a combination of incremental and radical innovations, giving it a mixed identity.

There is flexibility within the CCS sociotechnical system, where for example, there are multiple technical options for the different stages of the technology. For example CO_2 can be captured either pre or post combustion, it can be transported either by pipelines or ship and it can potentially be stored in depleted oil fields or deep saline aquifers. There is no set configuration for the CCS chain, and various combinations of the different technologies can be applied, depending on the social and technical context. Illustrative examples include a coastal power plant uses shipping transport to an offshore storage site, or an onshore facility can pipe CO_2 to another country for disposal. This added flexibility is useful for technology transfer and increases potential for application in different country contexts. However, this flexibility also contributes to the mixed identity of CCS, and therefore it is a challenge to consider CCS as a coherent technology. This lack of coherence made it more difficult for the UK government to market and promote CCS as a viable mitigation tool; there were far too many 'unknowns' and India felt that the technology was not yet ready to be deployed. A primary concern was that CCS had yet to be demonstrated at scale in developed countries, where several projects had been stalled due to rising costs involved or lack of public support.

Moreover, the mixed identity of CCS is also reflected in the political and economic dimensions of the technology, particularly as it builds upon the existing dynamics of sociotechnical systems such as oil and gas production, as well as electricity networks. These sociotechnical systems involve large national infrastructures, which imply the dominant role of the state, as well as commercial MNCs, which tend to operate across political borders. Therefore it is important to also consider the international political and economic objectives regarding CCS development. Technological political realism in particular highlights the dominant political influence of key developed nations, which have a strong history of hydrocarbon production and dependence, and this would allow them a competitive advantage.

In addition, it can be argued that CCS was marketed as a coherent technology, i.e. a simpler product than it really is. This was done in order to make it seem less challenging for technology transfer purposes. CCS was also specifically targeted at the markets of power-demanding emerging economies such as India and China. However, due to the mixed identity of CCS, it is open to interpretation, and therefore, some countries, notably the USA and China, have focused on the potential of utilising the CO_2 emissions. Notably, India also shows interest in using the CO_2 rather than storing it, and this shifts CCS away from the original central objective of climate change mitigation. CCS can therefore also be viewed as a product where the cost and risks can be accepted for both environmental and monetary gains. However, this mixed identity does not set a clear development pathway for CCS technology, and could have implications for its potential technology transfer to another country. As a result of its mixed identity, India was sceptical and did not accept the CCS vision set out by the UK Government. The following chapters focus in more detail in explaining why. Chapter Five details India's energy context, looking specifically at how CCS could be integrated into this system, based on the characteristics of the technology discussed here, and India's historical and current factors.

Chapter 5: India's Energy Context

5.1 Introduction

The previous chapter illustrates the complex and multi-faceted nature of CCS technology. Accordingly, if CCS were to become a part of India's energy system, then how can this be realised? How would this technology be received and integrated into the existing system? What are the challenges for innovation and deployment? These questions were being considered by the elite decision makers interviewed during the period of my research (2007-10). It was found that aspects of India's rich and complex history had a bearing upon the answers to all of these questions. The conceptual frameworks presented in Chapter Two provide a useful framework for analysis, and are discussed throughout this chapter under three general themes for understanding how India's historical and present context can influence CCS technology transfer: innovation; technology transfer; politics and international relations (IR).

This chapter aims to answer the questions raised above by reviewing notable historical events that have influenced India's technological innovation and how this has affected the development of its energy sector. The aim is to explore the historical and contemporary Indian context in order to understand the potential for CCS technology transfer in India. Providing broader historical context is crucial because of the close relationship between Indian culture and innovation, as observed by MacLeod and Kumar (1995):

> *"It is no mere coincidence that two great events, the Industrial Revolution and the process of colonisation, took place almost simultaneously… It all began with the expansion in commercial activities. The flag followed the trade, and both were conscious of the importance of scientific discoveries and technological changes. The story of India's colonisation is no exception to this rule."*
> *(MacLeod & Kumar 1995, p. 11)*

As previously discussed in Section 2.2.1, the theoretical approaches to technological change, innovation and the international aspects of these phenomena highlight an intricate and interwoven relationship between technology and society. Therefore, it is important to also consider the historical relationship between technology and colonialism, where "socio-economic changes are often influenced, if not determined, by particular technological events" and "colonisation affected the social, economic, political and cultural processes of both the colonised and coloniser" (MacLeod & Kumar 1995, p. 8 & 11). This is of particular relevance to India, which was under British colonial rule until 1947 and as a consequence colonisation has not only shaped India's energy sector, but has also influenced institutions for indigenous R&D as well as technology transfer mechanisms. Furthermore, how India's relations developed with the rest of the world post-independence gives clues to the international characteristics of India's receptivity to modern technology. These aspects are factors in determining whether CCS can be integrated into India's energy sector, particularly, as demonstrated in Chapters Two and Four, CCS R&D is largely taking place *outside* India.

With just over 60 years since it was carved out of the Indian sub-continent, India is a relatively young nation. Yet, the energy characteristics that defined the region under British rule still persist today. These include a disparity between urban and rural populations, each with different energy consumption patterns; a centrally controlled energy production system, where pre-1947 it was mostly owned by the British private sector, and now it is the Central Government; and lastly, a limited supply of resources for electricity generation. Resolving these issues is considered critical for achieving energy security and poverty alleviation, not only for India, but the region as a whole (see Ebinger 2011; Chellaney 2012).

In terms of direct CO_2 emissions, a sector-by-sector analysis by Parikh et al. in 2009 indicates that the majority of emissions (84%) come from six key sectors: electricity, manufacturing, steel, transport, cement and commercial services. Drawing on the discussions regarding the multiple identities, flexibility and applications of CCS (see Chapters 2 and 4) and it is apparent that CCS technologies could potentially be applied to a number of key industries in order to cut down CO_2 emissions. However, to better understand the challenges for CCS technology transfer to and within the Indian energy system, it is important to consider the historical events and decisions that have shaped and influenced the present-day energy system. The historical background also provides an insight into how India innovates, for example, the development of its National System of Innovation (NSI) and its current capabilities. As highlighted in Chapter Two, the NSI approach emphasises the importance of localised competence and learning (Lundvall et al. 2003) and that understanding a country's capacity for innovation is crucial for realising the potential of CCS technologies transfer to different country contexts. This also links with other approaches discussed in Chapter Two, regarding the movement of technology from developed to developing countries, through international relations and technology transfer mechanisms, which are key aspects of establishing a large sociotechnical system, but have been traditionally neglected in the literature (Fritsch 2011; Bridge et al. 2013). There are specific historical and political circumstances that have influenced such transfers, particularly in the context of India's energy sector, which are presented in Section 5.2. Furthermore, given the current status of CCS technologies (see Chapter 4), the current pattern of energy use and development within India's relevant sectors also indicates the potential for CCS technology application, especially in terms of early deployment. This discussion is presented in Section 5.3.

5.2 Energy History: Science & Technology Innovation in the Postcolonial State

Here I examine India's past, highlighting events that have not only influenced how India acquired technology and subsequently developed its own capabilities, but also shaped the energy system that is in place today. Analysis starts from the build-up to the Second World War, when India was still under British rule, to the newly independent state under Nehru's leadership, and through to an era governed by his daughter, Indira Gandhi, which was a time of significant nationalisation and protectionism. Finally, in the last decade of the 20th century a number of economic reforms were introduced, which led to a period of rapid economic growth coming into the 21st century. All of these periods in India's past have not only determined the state of the current Indian energy sector, but they also shaped India's innovation system and the relevant institutions and organisations supporting indigenous research and development (R&D), as well as how India acquired modern technologies through international transfer.

5.2.1 Pre-independence (Pre-1947): Colonial Science and Early Technology Transfer

In comparison to the “colonies of settlement”, i.e. Canada and Australia, India already had “a long and rich history of distinctive indigenous techno-scientific traditions” when the British arrived (MacLeod & Kumar, 1995, p. 9). However, under colonial rule, all science and technology related policy in India was designed and set by the British Government (MacLeod & Kumar 1995). However, science policy was not well-defined because it wasn’t considered necessary for the development of the colony, and even though there had been calls for the promotion of science in colonial India, particularly for the improvement of agriculture and industry, there remained a laissez-faire approach (Abraham 1998; Narasimha 2008; Rao 2008). MacLeod & Kumar (1995, p. 8) describe colonial science as being primarily concerned with the discovery of natural resources, where exploratory activities and research focused on “geology, meteorology, botany, agriculture and forestry”. Furthermore, MacLeod & Kumar (1995, p. 9) also highlight the importance of political drivers for science and technology policy during this period, which is described as:

> *“… a global system which by custom exchanged raw materials for manufactured goods, [where] the leading imperial question was how best to encourage local innovation and investment through technology and its associated skills, without losing control of its profitable and portable benefits.” (MacLeod & Kumar, 1995, p. 9)*

The established Indian universities of that period were predominantly focused on ‘scholarship’ rather than ‘research’, and trained subordinate personnel for colonial civil service (VijayRaghavan 2008). Nevertheless, a few individuals and leading business families were driving indigenous research and innovation, notably the Tata family, who with the help of the Maharajah of Mysore, established the Indian Institute of Science in Bangalore in 1909 (Piramal & Herdeck 1986; Narasimha 2008). These individuals were instrumental in establishing the foundations for India’s innovation system prior to independence. As the work of Hughes (1983) demonstrated, the role of individual actors whose support and promotion of particular technologies led to the electrification in the West, similarly, these historical figures were India’s ‘system builders’. The role of philanthropic individuals is still very culturally significant for

India's innovation, and the more current context is discussed later in Section 5.2.4. Therefore, this can be seen as an important aspect of how India develops technology, and will need to be considered when it comes to CCS. Both in terms of fostering innovation and having political power, it indicates that such system builders might be required within India in order to support a sociotechnical system such as CCS.

During and between the two World Wars, the colonial state conceded that modern science and technology was key to its national security. Even though Britain was keen to ensure that "no commercially or military sensitive technology became available to the 'natives'" (Narasimha 2008, p331), a number of ordnance factories and production facilities for defence goods were set up, in addition to the Indian Industrial Commission in 1916 and Munitions Board in 1917 (Abraham 1998). This is how 'modern science' was introduced to India, representing the initial method of technology transfer by which India acquired modern technology. By the time of WWII, and through to Indian independence in 1947, "the national question became one of deciding how best to transform modern modes of production and means of control into research organisations and institutions run by Indians, following agendas set by a democratic India" (MacLeod & Kumar 1995, p. 9). This period is marked by a surge in investment in indigenous research institutes and national laboratories, including the Indian Council of Agricultural Research (ICAR) (1929), the Council of Scientific and Industrial Research (CSIR) (1942), the Indian Council of Medical Research (ICMR) (1949), and significantly, the Tata Institute of Fundamental Research (TIFR) (1945), which pioneered India's nuclear energy programme (Abraham 1998; VijayRaghavan 2008).

The development of the electricity sector in the transition period from colonial rule to independence, set the tone for India's power sector for years to come. Commercial energy[44] was largely produced by private sector companies, which were British owned and operated (Ebinger 2011). The electricity mix consisted of coal, oil, and hydroelectricity, where most of the electricity produced was for industrial purposes

[44] Commercial energy is defined here as energy that can be bought and sold, and therefore easier to quantify; includes oil, gas, coal, hydroelectric power, nuclear power and renewable energy resources such as solar and wind. Non-commercial energy in this context would include resources that traditionally are not commodities, such as crop waste, wood fuel, and dried cow-dung.

rather than civilian needs, and "the hydro: thermal generation mix was almost 50:50" (Sudarshan & Noronha 2009, p. 11). In the lead up to independence, large-scale electricity production and distribution was minimal and confined to large cities such as Calcutta and Mysore (Ebinger 2011). Large thermal power plants were scarce during this period, and India's annual consumption per capita was just 1% of Britain's consumption, and India's total generation capacity was 1,500 MW (Sudarshan & Noronha 2009, p. 11).

Notably, this period of India's energy history illustrates how, as a post-colonial state, India inherited form the UK an existing sociotechnical system in the form of coal-based thermal generation and hydropower. In other words, its energy system was acquired under colonisation, where the institutions and infrastructure were influenced by the British regime. India has had a long history of international technology transfer in the energy sector, influenced by colonisation. The following sub-section considers this aspect further in the context of nuclear technology.

5.2.2 Post-independence: Nehru, Nuclear Power and the National System of Innovation

The previous section presents the foundations of India's energy system, highlighting not only the influence of British colonial rule, but also the importance of indigenous system builders. This combination of international technology transfer and indigenous R&D was also an essential part of the development of India's nuclear sector. The parallels and implications for establishing a similar sociotechnical system, such as CCS, are discussed in this sub-section.

Nuclear energy in India is relevant to CCS technology transfer because: (1) both are essentially competing options for base-load electricity generation (e.g. Tavoni & van der Zwaan 2011); (2) both have the capability to significantly reduce CO_2 emissions; and also (3) because there are parallels that can be drawn upon issues such as the significant role of the state, construction of large infrastructures and risks associated with geological storage (UKERC 2012). In terms of meeting India's *electricity* demand, all survey respondents listed nuclear as one of the top three important energy resources (Survey 2009, Appendix B). Nuclear power was considered as a vital contributor to the current electricity supply mix.[45] It is expected to have an even more important role in the future; it is anticipated that by 2050 nuclear would be ranked second to coal in importance according to survey respondents (*Ibid.*). Furthermore, during the study period of this thesis, nuclear was considered the top investment priority by the Indian Government in the context of developing a low-carbon future, demonstrated by the Indo-US nuclear deal (discussed further in Box 5.1). Notably, all survey respondents considered nuclear and solar as the key investment priority for the Government presently and over the next forty years, with CCS only becoming a priority after 2030, if successfully demonstrated elsewhere (*Ibid.*).

There are certain aspects of how nuclear technology was developed in India historically that can provide some insights into how CCS may or may not have a role within India's energy system. Firstly, I examine the impact of the system builder on the sociotechnical system. Science was considered to be an integral part of India's future, and a number of exceptional Indian scientists[46] were "a major cultural force that changed the country's perception of itself and its people's abilities" (Narasimha 2008, p. 331). Even before the first government of independent India was formed in August 1947, the Congress Party, lead by Jawaharlal Nehru and Subhash Chandra Bose, had deliberated upon issues related to science and national development and had established its own science policy (Narasimha 2008; Rao 2008). Nehru was also a great friend and collaborator to many of India's scientists at the time, in particular, the physicist Homi Bhabha, who pioneered India's nuclear energy programme. Together they had envisioned a future based on atomic energy for the country's development needs, and both went to great lengths to make it a part of India's energy system.

Both Nehru and Bhabha were akin to Thomas Hughes's 'system builders', and given the independence movement at the time, they are also considered to be part of the

[45] Majority of survey respondents (15/18) ranked nuclear as the third most important resource at present and through to 2030; Coal was ranked number one, and hydro as second (Appendix B).

[46] There were significant developments taking place in science due to the efforts of a number of exceptional Indians, even 75 years prior to Indian independence. Notable examples are H. Bhabha, J.C. Bose, S.N. Bose, C.V. Raman, S. Ramanujan, and M.N. Saha, who were all 'products of the ferment in Indian society, which motivated the struggle for freedom' (Mashelkar 2008, p300).

founding fraternity of India. Therefore, atomic energy can be associated with India's national identity as well as the institutions that are a part of India's NSI. When Nehru became India's 1st Prime Minister, he put in place a series of policies that dictated public and private participation in scientific and industrial development. Nehru believed that science and technology were tools with which "to transform a civilization in distress", and the solution for alleviating poverty (Narasimha 2008, p. 332). These beliefs formed the basis for his 'Scientific Policy Resolution,' proposed to Parliament in 1958:

> *"The dominating feature of the contemporary world is the intense cultivation of science on a large scale, and its application to meet a country's requirements. It is this, which, for the first time in man's history, has given to the common man in countries advanced in science, a standard of living and social and cultural amenities, which were once confined to a very small privileged minority of the population." (Government of India, 1958)*

Ideologically, Nehru was advocating a 'socialistic society', and a foreign policy of 'nonalignment', looking disfavourably upon foreign influence and admission of market capitalism into the country (Abraham 1998; Narasimha 2008). Therefore, he also put more emphasis on 'self-reliance' whilst developing the public sector and domestic private sector:

> *"Science and technology can make up for deficiencies in raw materials by providing substitutes, or, indeed, by providing skills which can be exported in return for raw materials. In industrialising a country, heavy price has to be paid in importing science and technology in the form of plant and machinery, highly paid personnel and technical consultants. An early and large scale development of science and technology in the country could therefore greatly reduce the drain on capital during the early and critical stages of industrialisation." (Government of India, 1958)*

However, this objective of 'self-reliance' actually stemmed from a number of science and defence strategies proposed to the Indian Government just before and after independence. A series of internal reports prepared by British scientists stressed the need for self-reliance in the design and manufacture of war materials, and were of the consensus that India should devise "the technological methods of her defence through growth in the institutions of science" (Abraham 1998, p. 56). One report in particular, by biologist A.V. Hill, who was Secretary to the Royal Society in 1944, suggested "a centralised system of scientific administration, expansion of the funds dedicated to scientific activities, and the formation of institutes of technology on the model of the Massachusetts Institute of Technology" (Abraham 1998, p. 55). This part of India' history is more reflective of arguments posed by Fritsch (2011) and Sylvest (2013), which is that the STS approach to understanding national infrastructure systems should also take account of the role of international actors and security drivers, issues focused upon by IR scholarship. Subsequently, Nehru's Government invested a significant part of its resources in creating quality institutions of higher education and research, including the establishment of the Indian Institutes of Technology (IITs) (Narasimha 2008). The Government also set up several modern industries in the public sector, including heavy electrical machinery, machine tools, electronics and telephones (Narasimha 2008).

Second, I consider the significance of international political relations on India's energy sector, specifically, nuclear electricity generation. The period reviewed thus far signifies the foundation of India's NSI, which entails key institutions, such as the aforementioned IITs that were formed then, and are still central to the country's innovative capacity today. This NSI was viewed for nearly thirty years as a model for other developing countries to follow, and it remains a source of national pride (Mashelkar 2008; Rao 2008; VijayRaghavan 2008). Furthermore, the NSI was capable of supporting and fostering innovation in India's atomic energy R&D programme. Box 5.1 (below) presents the historical foundation of India's nuclear programme, not only highlighting the socio-political drivers within the country at the time, but also demonstrates the importance of international linkages for technology transfer.

Box 5.1: India's love for nuclear power

Nehru had always been a strong advocate for science and technology, seeing it as a means for enhancing economic development and lifting his people out of poverty. He was even more passionate about nuclear energy; and his fascination with its potential was evident as soon as he became the Prime Minister of a newly independent India in 1947, two years after the destruction of Hiroshima. The timing of India's independence and "the sudden possibility of access to enormous and cheap sources of energy seemed too good to be true – it had to be divinely ordained" (Abraham 1998, p. 7).

> *"Atomic energy was an opportunity that could not be missed, both for its tremendous power potential and because it was one area where the most developed and least developed states would be beginning on relatively even footing." (Ibid.)*

Within one year after independence, Nehru had established the Indian Atomic Energy Commission (AEC) within the Department of Scientific Research, and by 1954 a separate department for atomic energy was formed that reported directly to the Prime Minister.

Nehru was also on very good terms with a renowned Indian physicist, Homi Jehangir Bhabha, who had returned from Cambridge just before India's independence. With the help of Bhabha's former colleagues in Britain, India was able to set up an operational reactor by 1956. Since this period India has been pursuing both conventional (natural uranium-based) and advanced (enriched uranium-based) nuclear energy technologies. Today, India has 20 operational reactors, with a combined capacity of 4,391 MW, and another 5 reactors are under construction, which have a combined capacity of 3,564 MW (Ebinger 2011, p. 46).

Bhabha's Thorium Strategy:

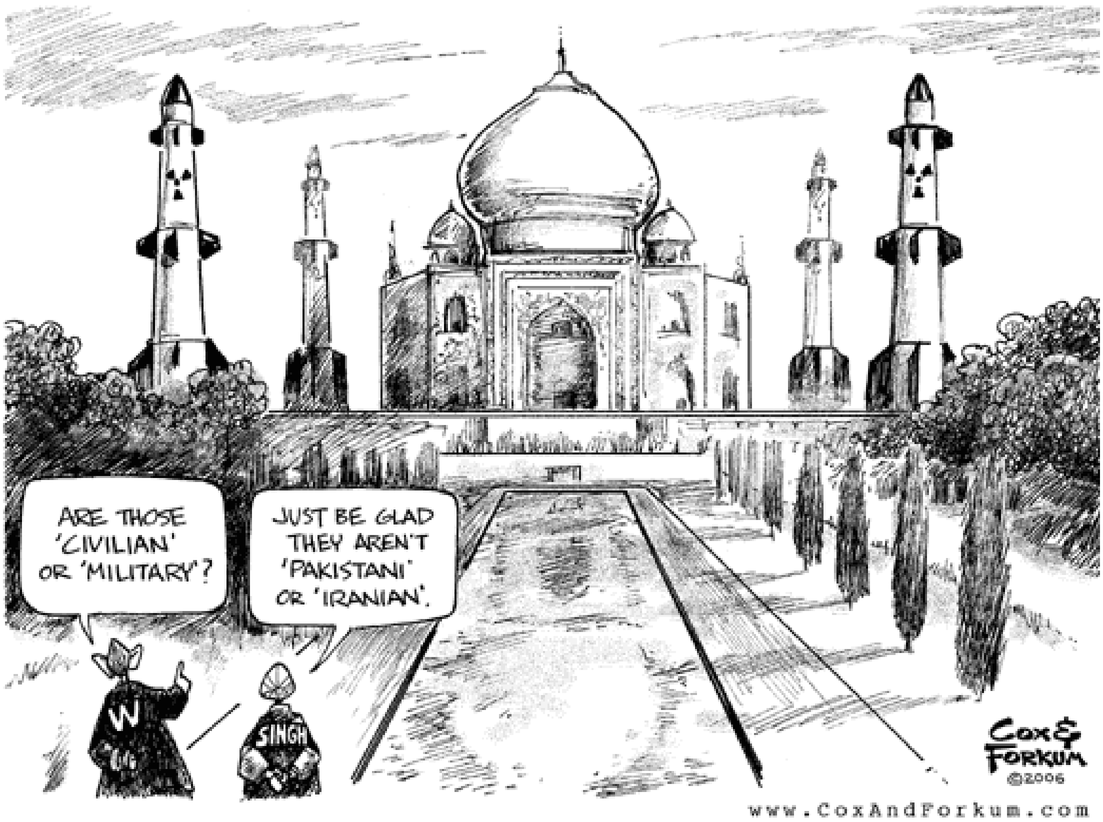
India's nuclear energy ambitions have always been about thorium. Although enough quantities of uranium had been discovered to power a few conventional reactors, by the mid 1950s the AEC realised that its most extensive resource was thorium (India has 25% of the world's thorium reserves). Bhabha had decided that any self-sustaining long-term strategy had to be thorium based, which could not be used directly as a fuel, unless combined with plutonium. And so came the idea for breeder reactors:

> *"Thus the first step to utilising thorium is to produce sufficient quantities of plutonium. Plutonium, which is produced in a reactor as an end-product of fuel burnup (regardless of whether the fuel is enriched or natural uranium), can be used to 'blanket' thorium in a second-stage reactor, allowing it to become fertile, and thus to produce the highly fissile isotope of uranium, U-233. The U-233 produced in this way can be used as fuel in a third stage 'breeder' reactor. The planned culmination of the Indian strategy was a family of breeder reactors fuelled by U-233, which because of the physics of these elements in the core, would produce as much new fuel as was being used up."(Abraham 1998, p. 92)*

However, for this strategy to work, India needed access to plutonium, which is best known for the first generation of military nuclear weapons: the atom bomb. And so, getting unimpeded access to enriched uranium had been impossible for decades. Bhabha and Nehru hadn't fully considered the political ramifications of this strategy. Nonetheless, it is important to note, "at the time of embarking upon this strategy, the technology for breeder reactors did not exist. The Indian AEC's long-term strategy was based on scientific principles – the physics and chemistry of atoms and its knowledge of the domestic resource base – not on the knowledge of existing technology" (*Ibid*.).

Indo-US Nuclear Deal:

With a change in geopolitics, two nations, who had once been at odds during the Cold War, are now working together to realise Bhabha's dream. The US-India Agreement on Civil Nuclear Cooperation was signed into law in December 2008. This provides India with access to the international market for civilian nuclear technologies, without having to sign the Non-Proliferation Treaty. As a result of this agreement, India is now able to source its uranium from other countries such as Mongolia, Russia and Australia. The aim of this agreement is to ensure security of supply for the nuclear fuel cycle associated with its thorium breeder reactor programme (Ebinger 2011, p. 46).



India is still very keen on a breeder reactor programme based on a thorium fuel cycle, and R&D has remained a priority for the Government. A fast breeder test reactor has been operating since 1985, and a 500 MW prototype fast breeder reactor is currently under construction. Though, public pressure has led to the passing of stringent legislation concerning civil liabilities from potential nuclear damage in 2010. This piece of legislation is particularly discouraging private international nuclear vendors because it "renders suppliers liable for damages" if they are considered at fault for an accident (Ebinger 2011, p. 47). However, state-backed companies are not so concerned, such as those in France, Russia and South Korea, as they are hoping the state will help cover the risk (*Ibid.*). Nevertheless, in the wake of the 2011 Fukushima earthquake, there has been substantial public opposition to the construction of nuclear power plants with mass demonstrations temporarily halting the construction of a joint venture plant with Russia in southern India (Bajaj 2011). Therefore, it may yet still be some time before we see the thorium-based reactors making a mark in India's energy system.

Even though India had comparable depth and talent to the West when it came to scientific expertise, Box 5.1 highlights the importance of international technology transfer as well as political drivers for supporting its nuclear ambitions. This is both for India's initial reactors, as well as for the current Government's development plans. Building upon the discussion in Chapter Two regarding the geographies of energy transitions, Bridge et al. (2013, p. 332) acknowledge the importance of international factors in innovation processes, i.e. the movement of technology beyond national borders. For such shifts to occur, the political relationships between different countries are a key determinant for technology transfer (see Herrera 2006 & Fritsch 2011). For example, Box 5.1 illustrates how existing relations with Britain at the time of independence influenced the development of India's first operational reactor. However, during the cold war, India's relations with the Soviet Union were strengthened through technology transfer (Mehrotra 1990), which was looked upon unfavourably by the USA, and the political ramifications of this relationship slowed down the development of India's nuclear capabilities (Abraham 1998). In terms of IR theory, this period of India's energy history can also be viewed through technology politics with a realist lens, demonstrating how interstate competition for influence and power is a strong driving force behind technology transfer and development. However, the events described in Box 5.1, as well as the earlier discussion on Nehru's National vision indicates how a government's survival, legitimacy and pride can be strongly linked to technological innovation and development. This builds on the work of Street (1992) on the central role of the state as customer, regulator, and underwriter of technology, and also the approach of Fritsch (2011), who highlights the reciprocal nature between technological development and politics and international relations (see Chapter Two).

Furthermore, the case study in Box 5.1 also showcases India's capability to innovate and develop the beginnings of its own particular type of nuclear sociotechnical system, which was envisioned by Bhabha through his thorium strategy. Civil nuclear technology is poised to have a significant role within India's development plans and ambitions for a low-carbon energy sector, and is also considered to be important for energy security reasons (Ebinger 2011). Given these drivers, within India nuclear is positioned as a strong alternative to coal with CCS.

5.2.3 Post-independence (1947-1989): Nationalisation of the Energy Sector, Industrialisation and System Entrapment

The previous section describes how Nehru set out to establish India's NSI and explores the case of India's civil nuclear programme, and its implications for CCS technology transfer. Over the years post-independence, India was set on a path towards industrialisation, and the Indian state became more significantly involved with national infrastructure systems. This period of history has consequences on the existing energy-related sectors to which CCS would need to be applied to. This section explores some of the issues of this period in India's energy history that presented challenges to contemporary CCS technology transfer in the period 2007-2010.

India gained independence amidst destruction, violence and chaos when partitioned into Pakistan and East Pakistan (now Bangladesh). Faced with huge development challenges, there was a major drive for electricity generation for nation building and to boost new industrial growth. Since colonial rule, the technology for coal-fired thermal plants and hydroelectric power was readily available, and therefore, naturally became the starting point for independent India's power sector. In addition, one of the legacies of British rule was an excellent railway network, which was ideal for transporting fuel throughout the country, and so gave another advantage to coal use (Sudarshan & Noronha 2009). Still, private British firms had originally controlled coal production, and consequently Indian coal producers had to rely on outmoded technologies and production techniques after independence (Ebinger 2011). It could be argued, that unlike nuclear, which symbolised national innovation, coal-fired thermal plants were an inheritance from the Raj, and this cultural context has subsequently influenced the competition between the two technologies (Interview A1 2008; Interview B6 2008; see also discussion in previous section). Such aspects clearly demonstrate the sociotechnical nature of technology development.

Prior to independence, private sector investment was not forthcoming, and therefore had not "developed the capacity to support such a robust industrialisation agenda", and therefore the responsibility for setting up the energy industry fell largely on the public sector (Ebinger 2011, p. 21). Subsequently, Nehru introduced the Industrial Policy Resolutions of 1948 and 1956, as well as the Electrification Act of

1948, where collectively, these policies expanded the Government's role and gave significant state control to key energy and industrial sectors such as hydrocarbon production, nuclear energy, electricity generation and distribution, and steel production. The Electrification Act of 1948 in particular gave almost exclusive control to the state; it created the Central Electricity Authority (CEA) to develop a comprehensive electricity policy, and the state electricity boards (SEBs), were responsible for integrating utilities that produced and distributed electricity at the state-level (IEA 2002b). The measures within this Act resulted in the publicly owned share of electricity capacity to increase from 42% in 1951 to 65% over the next decade (Ebinger 2011).

Within this period India achieved very little progress in terms technological innovation in the power and coal sectors, and some of the inefficient power stations and labour intensive mining practices from this period are still present in today's energy infrastructure (IEA 2002a; IEA 2002b; Chikkatur 2008; Sudarshan & Noronha 2009). According to Ebinger (2011), post-independence India's public-sector coal production became an 'unscientific process', where Government targets could not be met. Reasons included inadequate geological data as well as poor decisions made by the Indian Government:

> *"The Nehru administration staffed a number of industry and energy organisations with bureaucrats rather than business and technical experts; as a result, state-run industrial organisations, including those involving hydrocarbon production and electricity generation and distribution, were largely underfunded and poorly staffed." (Ebinger 2011, p. 21)*

Similarly, even after establishing the Indian Bureau of Mines, the National Coal Development Corporation and expanding the Geological Survey of India, coal production from the public sector fell short of its target out of the total set by the Government[47]. The oil and gas sector was in a similar situation, where the Government's Oil and Natural Gas Commission (ONGC), formed in 1956, could not

[47] In 1956, the Government's second five-year plan set a coal production target of 55% from the public sector, but in practice only 36% could be achieved (Ebinger 2011).

boost public sector production, even though it was given exclusive onshore exploration and production rights (offshore fields were already under production by the private sector) (Ebinger 2011). It is important to note that the fossil fuel related sectors were developed from existing systems, inherited at the time of independence, and therefore, it could be argued that India was already set on a pathway to carbon 'lock-in' (Unruh 2000) since its inception (see discussion in Section 5.3).

Further initiatives for nationalisation were taken up by Nehru's successors, most notably under his daughter Indira Gandhi[48], whose policies had a significant impact on national development for more than twenty years, until liberal reforms commenced in 1991. From 1947 through to the 1980s India's economy grew only 3% a year[49]; with a similarly slow growth for the following decade, India's 'development performance' was considered 'as less than satisfactory' (Arun & Nixson 2000, p. 19). This performance has been linked to the more protectionist approach taken by the government in regards to its science and technology policy in the 1980s (Arun & Nixson 2000; Lall & Urata 2003). The objectives of the Technology Policy Statement of 1983 were to focus on more 'self-reliance' and 'development of indigenous technology', as well as 'the efficient absorption and adaptation of imported technology appropriate to national priorities and resources' (Government of India 1983). And so, compared with most other developing countries at the time, India had some of the strongest scientific and technological institutions in place, though there was little benefit to the country's industrial sector (Krishnan 2003).

In the energy sector in India during this period the public sector gained further control of key energy industries. In particular, the coal sector went through 'a two-stage nationalisation process', where the public sector share of overall production went from 35% in 1971-72 to 53% in 1972-73 and then to 'a staggering 97% in 1973-74' (Ebinger 2011, p. 24). The sector grew based largely on international technology transfers. The Soviet Union was one of the largest trade partners, contributing

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[48] Nehru passed away in 1964, and his daughter Indira Gandhi served as Prime Minister for two terms (1966-1977 and 1980-1984).

[49] Historically referred to as 'the Hindu rate of growth'.

significantly to India's industrialisation through projects relating to coal mining machinery, oil exploration and refinery equipment, turbines, steel and aluminium plants etc. (Mehrotra 1990). This was coupled with heavy subsidies for certain petroleum products, chiefly diesel, along with LPG and kerosene, leading to the 'dieselization' of the Indian industry (Ebinger 2011). Diesel became a crucial fuel; not only for the transport sector, but also for off-grid power generation by industry, as electricity availability from state facilities was becoming more and more unreliable. Towards the mid-1980s, India's electricity sector was the most inefficient and unprofitable in all of Asia, operating at an average of 23.5% plant-based efficiency, where "even Bangladesh, by no means a beacon of power efficiency, operated thermal plants above 25%" (Ebinger 2011, p25).

This period of strong nationalisation in India's energy history illustrates the marked increase of 'centralisation' in the administration of key energy-related sectors, indicating the rise of the role of the state. As noted by Street (1992), there is a reciprocal nature to the relationship between the state and technology: industrialisation via technology transfer was crucial for the development of India post-independence, but at the same time the government's survival depended on their ability to develop the technology.

Furthermore, in terms of innovation, this period reflects the observations of Walker (2000) on the 'entrapment' or 'inertia' associated with mature technological systems in both developed and developing countries (see Chapter Two). This is an important consideration in relation to this thesis because these are the sectors that prospective CCS technology transfer would have been connected to. In addition, this period also shows a marked reduction in technological innovation, particularly in the key sectors of coal and power generation (see Chikkatur 2008; Sudarshan & Noronha 2009; Ebinger 2011). Again, this fits in with Walker's argument of system inertia (see Walker 2000), particularly when the state becomes a significant actor, and therefore has enough influence to hinder the effective adaptation of new technologies or different technological pathways. Therefore, this kind of institutional environment, which still persists today, posed a challenge to any potential CCS technology transfer in the period 2007-10; CCS was perceived as a threat to the status quo.

Despite the inward-looking stance of India's technology policy, extensive international technology transfers took place during this industrialisation period, and the type of contract depended on the collaborating nation. For example, earlier proposals with the USA on the Bokaro steel plant (1980s) were essentially on the basis of material transfer or turnkey contracts, where the training was only provided at the operational and maintenance level but not at the design or construction stages. Also it was expected that the US Steel Corporation would not be handing over control to Indian management till after a period of five to ten years (Mehrotra 1990, p. 78). This type of transfer has a tendency to 'black-box' technology, preventing innovative activity (see discussion in Chapter Two, Section 2.3.3). In comparison, the Soviet proposal, like the Americans, put design and construction control "almost exclusively in Soviet hands" though "management remained in Indian hands from the beginning", making this a "near-turnkey" contract (Mehrotra 1990, p. 78).

These technological choices were strongly influenced by the wider geopolitics at the time. Significantly, during this period of history India had fought two wars with Pakistan (1965 & 1971), and its relationship with the US deteriorated; the US declared Pakistan as an ally, pushing India towards the Soviet Union and its socialist policies. These events in the 1960s pushed India further towards nationalization and introverted policies, in addition to increased defence spending and raising public debt (see Noronha & Sudarshan 2009; Ebinger 2011). Both Mehrotra (1990) and Abraham (1998) highlight particular events that took place, specifically the India-Pakistan war of 1971, but also the overarching power struggle in the region between China-Russia-USA, which strengthened India's relationship with the Soviet Union rather than the US, and hence its earlier infrastructure and design of the energy sector is heavily influenced by R&D capabilities of the Soviet Union. This included construction and design choice of power plants, turbines, and fossil-fuel extraction methods, which were all key elements of Indo-Soviet technology transfers at the time (Mehrotra 1990). This is an example of not only the interstate competitiveness for influence, i.e. realism, but also illustrative of the 'external' international shifts that impact the geographies of transitions (see Bridge et al. 2012).

The following section moves away from the energy sector, to explore in more general terms a period lasting nearly twenty years prior to the period of study for this thesis, showing how India has formed its own style of innovation.

5.2.4 Economic liberalisation and India the international innovator (1990-2007)

Previous sections have highlighted the significant role of the Indian state in establishing its national energy infrastructures. Yet how does this impact the way India innovates today, especially in relation to CCS? What changed to take India from the poor third world country with the 'Hindu rate of growth' to the emerging economy, internationally known as a technological innovator? This section answers these questions by examining India's remarkable economic growth leading into the 21st century, and the implications this has had for CCS technology transfer.

In 1991 there was a change in government, which brought in radical economic reforms, including liberalizing many sectors within the economy, encouraging private sector participation, and creating more efficient means of public sector investment (Arun & Nixson 2000). It is during this period that the private sector, coupled with Foreign Direct Investment (FDI), started investing more in R&D activities. The services sector made the greatest contribution to the economy post-liberalisation, growing at the annual rate of over 8% from 1997-2002, which was double the rate of the industrial and manufacturing sector (Krishnan 2003; Dutz 2007). This included a great number of Indian Institutes of Technology (IIT) alumni that had made their fortunes in Silicon Valley (USA), and who began to invest in the Information Technology (IT) sector in India, an area where there was hardly any government intervention (Das 2002). Consequently, the IT services sector today accounts for over half of India's GDP, leading some analysts to conclude that the country has by-passed an industrial phase and transitioned directly to a service-dominated economy[50] (Kirshnan 2003). This is important to consider when thinking about innovation potential in other sectors, such as energy. Unlike the Indian energy sector, the IT sector has had very little state intervention. It suggests that India has the potential for a particular innovation style,

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[50] India currently has only half the manufacturing rates of other transition countries such as China and Malaysia (see Dutz 2007).

separate from the structured NSI approach demonstrated by policies under Nehru, which might also influence the way India innovates in other less regulated sectors.

Research shows that India does have the capability to innovate, though not in the orderly fashion usually associated with countries such as Sweden or Japan (Bound 2007). Often described as a 'license-Raj', India is encumbered with a highly inefficient bureaucracy, which is associated more with its more mature systems, such as energy. This phenomenon is epitomised by India's IT industry, which grew before the government understood what it was (see Das 2002).

Another symbol of India's innovation is a contraption of Punjabi origin, known as the *Jugaad* – an improvised vehicle, usually constructed by carpenters by fitting a diesel engine on to a cart, and used in rural areas (see figure 5.1). *Jugaad* is also a Hindi term for creative opportunism from meagre resources, and is used as much to describe enterprising street mechanics as for political fixes. As with innovation, three key constraints are needed in order to invoke *Jugaad*: space, time and resources. The difference is usually a greater level of urgency, and solutions are not for the long-term; it is entirely made for the moment, where efficiency (and aesthetics) takes a back seat.

Figure 5.1: A typical Punjabi *Jugaad*. Photo courtesy of Rajesh Vora

Despite that, India's *Jugaad* mentality has produced some notable low-cost innovations, such as the *Nano*, the world's cheapest car made by the dynastic Tata Motors. As discussed in previous sections, individual actors have had a considerable impact on India's innovation system, particularly the presence of powerful business families, who have historically contributed significantly to the country's R&D activities. The Tatas, Ambanis and Birlas have played roles as noteworthy as the Carnegies, Rockefellers and Fords did in the US (Piramel & Herdeck 1986). These industrialists also actively engaged with international firms under technology transfer initiatives, which started with near-turnkey or licensing contracts that were quickly adopted with in-house projects (as discussed in previous section). Therefore, what started out as frugal engineering and improvisation is now considered a savvy business approach for maximising resources, where *Jugaad* is a widely accepted method for low-cost R&D, and is becoming a popular innovation and management strategy globally (Radjou et al. 2012).

Conversely, there are calls for India to move away from the *Jugaad* mindset altogether. A more systemic approach to innovation is being encouraged, particularly for addressing bigger societal challenges, such as developing cleaner energy technologies. This includes critical reforms to public R&D institutions, crucially addressing the social barriers to innovation, such as the hierarchical structures and non-questioning culture within India's education system (Krishnan 2010). This approach may be more appropriate for supporting innovation for CCS technology in India because it aims to tackle the issues associated with system entrapment or inertia, which could potentially block any type of transfer (discussed in the previous section).

However, it could be questioned how useful it is to compare the innovative style of a nascent sector of IT services with a mature sociotechnical system such as power generation, transmission and distribution. What are the implications of private sector innovation in the IT sector for CCS? The effect of energy liberalisation policies that were introduced during this period was quite significant – allowing for much greater private sector investment – and the impacts began to properly manifest in the years leading up to and during this study, i.e. the economic boom from 2005-2010 (see Chapter 1, Section 1.1.1). In terms of innovation in the energy sector, Prime Minister

Narasimha Rao and Manmohan Singh, his finance minister at the time, brought in reforms to India's hydrocarbon industry, whereby domestic exploration and production was opened to the private sector; by this time the cost of imports were increasing due to, *inter alia*, the oil shock in 1991 prompted by the First Gulf War (Ebinger 2011). Nonetheless, pricing policies and obstructive regulations discouraged foreign investment, until the New Exploration Licensing Policy (NELP) was introduced in 1997, which initiated the necessary technology transfer of more modern and efficient processes within the energy sector (Carl et al. 2008; Ebinger 2011). NELP has been crucial for bringing in a significant amount of investment into India, as well as the much-needed technological knowledge and expertise; it is directly responsible for the recent discoveries of domestic oil and gas by the international firm Cairn Energy (Interview C3, 2008). This is an example of how the NELP policy has impacted international technology transfer projects in the relevant sectors for CCS application, e.g. fossil fuel refinery operations, pipeline transport structures, and offshore operations in general. Most notably, this type of technology transfer involves more knowledge exchange through joint ventures and other types of capacity transfers, which in the long run foster indigenous R&D and innovation.

The sudden economic boom in the period 2005-07 discussed in Chapter one (see Section 1.1.1), meant that a reliable and robust energy infrastructure is essential to India, to maintain this kind of development trajectory. It was apparent that India's energy sector had to provide the back bone to upcoming innovative sectors, such as the IT services industry, and consequently meet the growing energy demands associated with increasing economic development (Interview A1 2008; Interview B6 2008). However, it was also recognised that the environmental consequences of meeting the increased energy demands also needed to be addressed; and it was within this context and this period that CCS was being promoted internationally as an option for carbon abatement. The context of CCS technology transfer to India is considered further in the following section, which explores some of the challenges and opportunities within India's contemporary energy system.

5.3 India's Current Energy Use, the Coal Raj and Carbon Lock-In

Previously, it was discussed how India's history has shaped its energy system, and this section looks at the current rate of energy consumption in the crucial areas of electricity generation and industry, which are heavily reliant on fossil fuel. Also, presented is analysis of the contemporary energy sector, with a focus on present CO_2 emissions, infrastructure, and the state of India's natural resources, specifically coal. All of these aspects are important to consider when examining the social and technical feasibility of CCS technology transfer. This section discusses the specific characteristics of India's energy sector that created challenges for CCS implementation in the period 2007-10.

Out of the total CO_2 emissions of the Indian economy over half (57%) are from the use of coal and lignite (Parikh et al. 2009). As expected, the energy intensive sectors of electricity, manufacturing, steel and cement made up 91% of the direct CO_2 emissions from coal use (Parikh et al. 2009), and this trend amongst the different industrial sectors is expected to continue for the next 20-30 years, as the Indian government develops the country's infrastructure (TERI 2006; IEA 2007; Planning Commission 2011).

In 2008, India was ranked fifth in the world in terms of total primary energy consumption[51], and the IEA expects this to double by 2030 (IEA 2011c). India's economy is heavily dependent on fossil fuels, where a large portion of the energy demand is met by coal. The total primary energy consumed by India in 2008 was around 621 Mtoe[52], where the largest share (approximately 40%) of the primary energy source was coal (see Figure 5.2)[53] (IEA 2011c). The second largest share is provided by biomass, and it is an indication of India's large rural population, which is

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[51] Primary Energy is defined here as the energy directly embodied in natural resources, before being converted or transformed for use (Cleveland & Morris 2006)

[52] Megatonne (1 million tonne) of oil equivalent

[53] The data from formal assessments of energy use tend to ignore the off-grid diesel power consumed by a large number of small businesses and individual households and, this proportion is difficult to estimate.

the largest in the world (828 million people in 2008) and relies mostly on non-commercial energy such as waste vegetation and dried cow-dung (Sethi 2009).

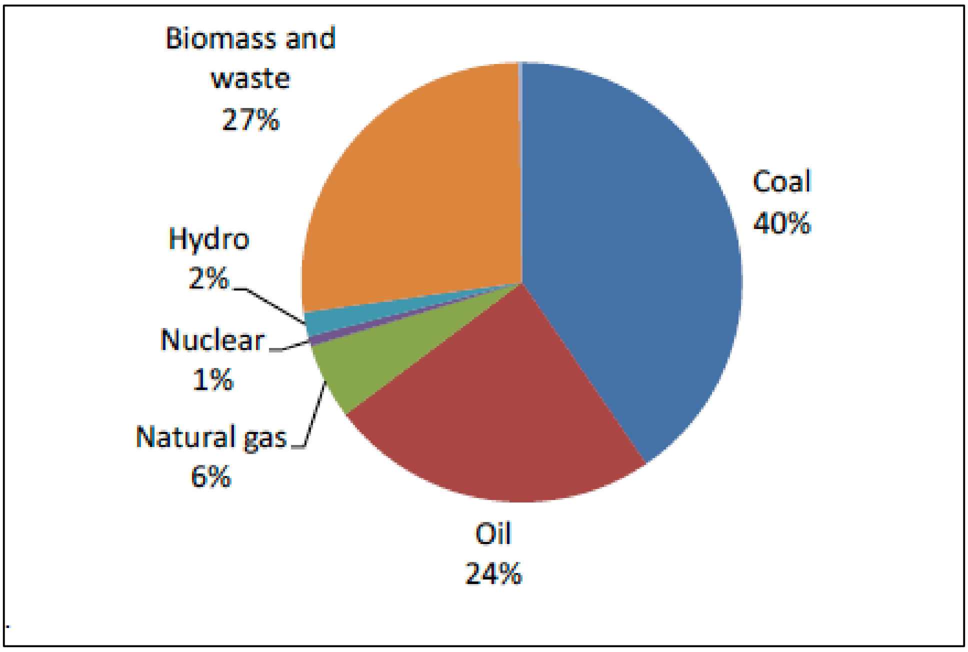

Figure 5.2: The breakdown of the total primary energy supply in India in 2008 (621 Mtoe) (source: IEA 2011c).

Even though Indian researchers (see TERI 2006) and Indian policymakers (see Planning Commission 2006) use differently configured models and data, the consensus is that India's future in the next thirty to fifty years is inextricably linked to the major use of fossil fuel. Coal production in India is essentially a monopoly, dominated by Coal India Ltd. (CIL), a public sector enterprise that employs over 450,000 people, and consequently has a powerful lobby (Sudarshan & Noronha 2009). Therefore, any reforms that could force competition, change labour laws, or reduce the importance of CIL in any way, are always met with strong opposition (Ebinger 2011). This has implications for introducing a technology such as CCS into an energy system heavily reliant on coal; the technology will need the support of a politically powerful faction, notably the CIL. CIL indicated that they were particularly interested to see how CCS developed in other countries, because it allows coal to remain within the supply mix, and would prolong the importance of coal within the energy system in the future (Interview B2, 2008). However, it was also noted that the Ministry of Power had the greatest influence over the Government's current position on CCS, even more so than the Ministry of Coal or CIL[54], adding that India was not obliged to cut its carbon emissions, therefore it was unlikely that CCS would have a role to play till much later (20-50 years), if those conditions changed (Interview B2, 2008). Survey respondents held similar views, ranking CCS as third, after nuclear and solar, when it came to Government investment priorities by 2030 and 2050 (Survey 2009, Appendix B). One respondent stated that "CCS will eventually become important for India, but not until the technology has been developed and demonstrated in the US, Europe and China" (Respondent 10, Survey 2009, Appendix C).

Moreover, with both supply (through CIL) and demand (power companies) being almost exclusively under government control, the price of coal has been kept below global prices, and therefore continues to be (artificially) cost competitive (Sudarshan & Noronha 2009). Therefore, with the restriction on foreign investment, coupled with a belief that India's coal supplies are limitless, there is a sense of complacency within the energy system (Carl et al. 2008; Ebinger 2011). A central finding is the paramount role of the Indian Government in these key sectors for CCS. There is evidence of technological determinism linked to this important role of the state, where the technology, in this case power generation from coal, has established "a particular set of power relations" (Street 1992, p. 31). This points to a situation described by Geels (2011, p. 25), whereby any changes to technology and the related sector would require changes in policies, and this in turn "entails politics and power struggles, because vested interests will try to resist such changes". Building upon that, Walker (2000, p. 834) argues further that in a mature sociotechnical system, powerful individuals or organisations can sometimes reduce diversity and create "technological monocultures" in order to ensure the survival of their particular organisation or "preferred solutions". In terms of innovation and technology transfer via foreign investment, CCS needed to have strong political support from powerful state actors, such as the Ministry of Power, in order to have a chance of being integrated into the energy sector during the period of study, 2007-2010.

[54] Notably, the work of Narain (2007) also highlighted that certain ministries in India wield more power than others, the Ministry of Power being the most influential out of the other energy related ministries.

The circumstances described above also resonate with the discussion in Chapter Two regarding Unruh's (2000) concept of 'carbon lock-in', and, more specifically, regarding the 'globalizing carbon lock-in', where, due to historical development paths coupled with accelerated industrialisation, transition economies such as India will struggle to escape carbon lock-in (Unruh & Carillo-Hermosilla 2006). Therefore, the case for integrating CCS technologies into India's energy sector becomes stronger given the imperative need to de-carbonise. However, there are a number of sociotechnical challenges specific to India's energy sector, which were identified as having impeded CCS technology transfer, and these are presented and analysed below.

5.3.1 India's Coal Supply

Given that coal is the predominant fuel for India's energy sector, coal production plays a significant role within India's energy system. If CCS technology transfer to India were to occur, then carbon capture technologies specifically designed for coal-based thermal generation would be needed. Therefore, this section looks at the current technical issues surrounding India's coal reserves, as this directly impacts the type of innovation and international transfer of CCS technology.

After the USA and China, India is the world's third largest producer and consumer of coal, and it has plans to remain an important player in the world coal market (see IEA 2007 & IEA 2011a). However, the current supply of indigenous coal is unlikely to meet the demands of the growing economy, and India has now become a significant importer of coal. According to a regional exploration and resource assessment in 2005 that was commissioned by India's Ministry of Coal, out of a total coal resource of 248GT, only 38%, or roughly 93GT was considered as 'proved resources'[55] (Ministry of Coal 2006). However, Chikkatur et al. (2007) highlighted several problems with the Indian coal resource assessments, such as the inclusion of reserves that are already

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[55] The Indian classification system of 'proved resources' is primarily based on geological evaluations without assessing the quality, mineability, or extractability of deposits. In contrast the United Nations Framework Classification (UNFC 2004) denotes 'proven reserves' as the part of the remaining resources that is economically mineable, technically extractable, and geologically proven (see Chikkatur 2007).

depleted due to mining, and resources that cannot be mined due to surface and geotechnical constraints. Moreover, Chand (2007) noted that the analysis of India's coal resource does not include those at deeper depths. Subsequently, 62% of the explored coal resources occur at shallow depths (0-300m), which is essentially the depth accessible through opencast mining (Ministry of Coal 2006; Chand 2007; Chikkatur et al. 2007). The Central Mine Planning and Design Institute (CMPDI)[56] estimated that only 52GT (56%) out of the 93GT of proved resources can be considered as extractable[57] coal (see Ministry of Coal 2006). After the Ministry's assessment, India's Planning Commission has since then increased the estimated range of extractable coal reserves to 56-71GT (Planning Commission 2006). Given the discrepancies between the classification of reserves, and that nearly 8GT of coal has already been mined, other analysts have brought the Government's tentative estimates down to roughly 44GT (Chand 2007; Chikkatur 2008).

The key point is that with these estimates, and depending on the rate of domestic production and use, a relatively short lifetime is projected for India's coal reserves, lasting for the next 30 – 60 years (Chikkatur 2008). The interviewee from CIL emphasised that mines were already being operated unsustainably to cope with increased demand, and believed that with current rates of consumption, the extractable coal is likely to run out by 2030, unless deeper coal seams are exploited, for which the technology is currently unavailable in India and it is a more costly process (Interview B2, 2008).

These projections are substantially less than previous estimates from international organisations such as the IEA, which assumed Indian coal supply could last nearly 275 years (IEA 2002), or the BP Statistical Review of World Energy in 2007, which listed India's proven reserves to production ratio as 207 years (BP 2007). Researchers have indicated that these inflated estimates, coupled with discrepancies in the national classification system, have given Indian policymakers a false sense of security:

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[56] The CMPDI is a subsidiary of Coal India Ltd, and is a Government of India's public undertaking.

[57] The term 'extractable reserves' is almost equivalent to UNFC's 'proven reserves', however these estimates still include depleted reserves.

> *"The comfortable, opiating belief of possessing huge quantities of coal has contributed to a stagnation of energy policy initiatives and an insufficient investment in research and infrastructure that might have aided the use of alternatives such as natural gas or distributed renewables." (Sudarshan & Noronha 2009, p12)*

Therefore, the idea that India's indigenous coal reserves are vast, and plentiful enough to meet the country's needs for hundreds of years, still persists within certain energy institutions, both nationally and internationally (Ebinger 2011). It helps explain why there was a push from the international community for CCS technology as a mitigation option for industrialising countries, particularly those with coal-based economies such as India and China. In other words, in addition to being a method for decarbonising their own energy sectors, developed countries such as the UK and the USA viewed India and China as prospective customers of CCS technologies due to their large coal reserves (see also Chapter Four).

The foreseeable shortages in the future remain largely unacknowledged, and coal is set to remain the dominant fuel in India's future planning for their energy system. For example, the Chairman of the Expert committee on Coal Sector Reforms stated in a report to the Ministry of Coal:

> *"Our analysis contained in the Report establishes beyond any reasonable doubt that coal should be considered the primary source of energy to the country. The coal resources of India, in spite of the quality being poor and their unevenness in geographical dispersal represent the most valuable and reliable source of energy to the economy." (Ministry of Coal 2006, p. 1)*

Even though the Ministry of Coal encourages the Indian Government to consider coal as the primary source of energy to the economy, it has noted that there is a substantial gap between supply and demand. The committee recommended a thermal coal import of around 30-40 Mt of high-grade coal by 2011-12 as a short-term measure (Ministry of Coal 2006). Typically, India has relied on imports of coking[58] coal for its

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[58] Coking coal is a high-quality coal, i.e. low-ash content and limited volatile matter (e.g. benzene, propane and sulphur gases). When heated in the absence of oxygen it is 'coked', producing a hard

steel industry, owing largely to the high ash content and high moisture content of Indian coals (IEA 2002a). However, there has been an increase in the imports of non-coking[59] coal to meet the shortfalls in power generation, and this trend is likely to continue and exceed coking coal imports. It is anticipated that India will import nearly 114 Mt of coal by the end of the fiscal year (2012), compared to 82 Mt in 2010/2011 (Mukherjee & Lalmalsawma 2011) and 73 Mt in 2009/2010 (Singh 2010).

Consequently, India is in the midst of a coal crisis, where domestic production cannot meet demand, and acute shortages of coal plus rolling power blackouts are common place. Almost a third (30 out of 95) of India's power stations are currently running on less than a week's worth of coal stock, and a further 19 power stations are running on only four days of coal stock (Indian Express 2012). In comparison, between January 1995 and October 2009, UK power stations kept on average a monthly stock level of 95 days, where the minimum was 29 days in March 1996, and the maximum was 342 days in August 2009 (Wilson et al. 2010, p. 4101). Aside from the uncertainty of reserves and the low production rates, another reason for these shortages is due to logistics.

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and porous material. This coke-fuel is used largely for industrial processes such as steel manufacturing.

[59] Non-coking coal does not have the chemical properties that allow it to be 'coked' (see previous footnote). It is largely used for thermal power generation.

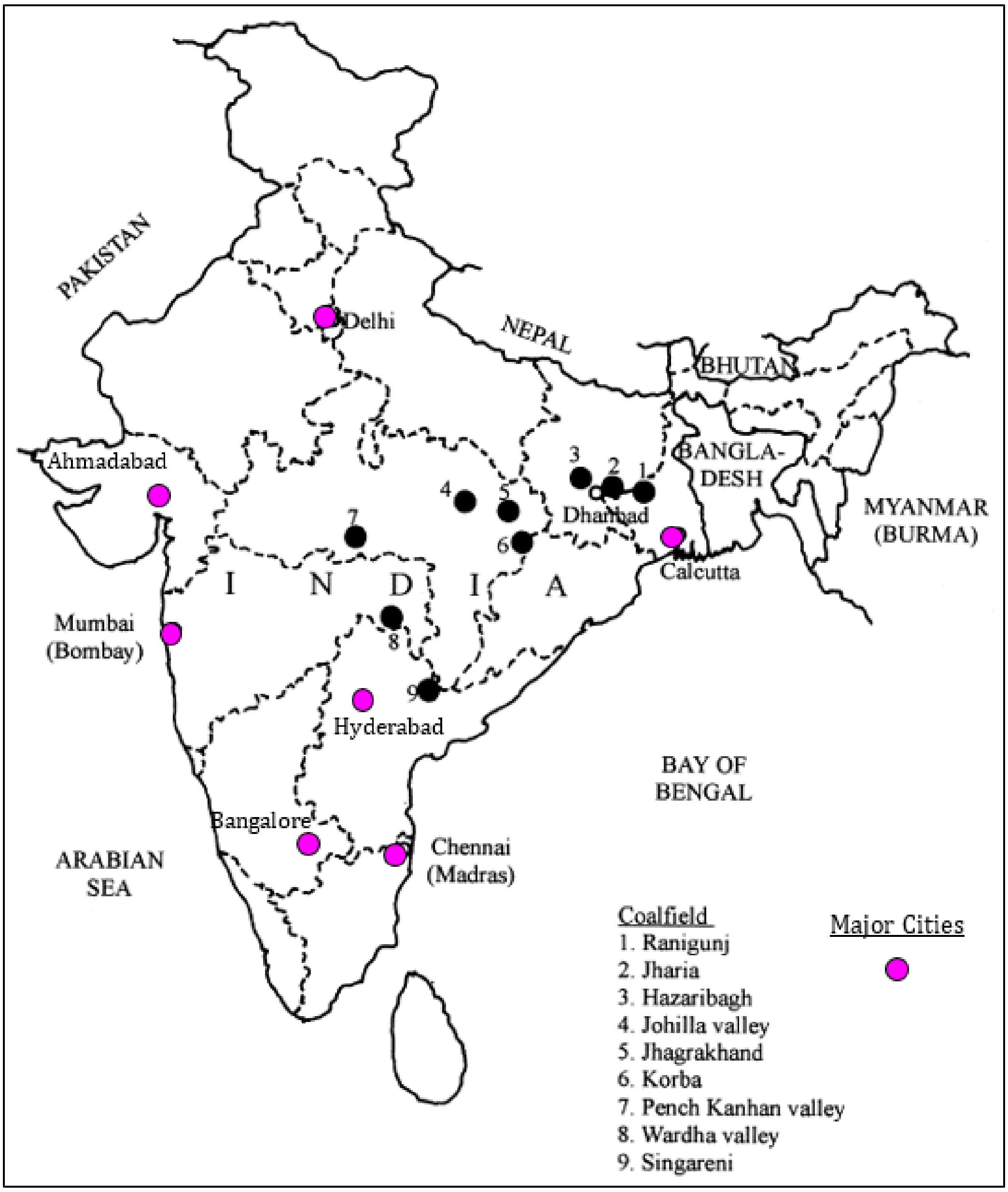

Figure 5.3: Map of India's main coal-fields and major cities (population: 4+ million) (map adapted from Sheorey et al. 2000).

As shown in Figure 5.3, the majority of India's coalfields are in the north and east of the country, and far away from the main urban centres of demand. Consequently, many power plants in the south and the west prefer the cost-competitive option of imports, as they are close to key ports, and "because India's coal logistics system is so antiquated that often it is difficult to get coal to those end-use markets on a timely basis" (Ebinger 2011, p. 36). Furthermore, it has also been observed that the poor quality of Indian coal can at times lead to spontaneous combustion, where substantial amounts of fuel are lost before it reaches the market (*Ibid.*).

Given these general conditions of India's coal sector, then there are two things of note to consider in regards to CCS innovation and technology transfer pathways. Firstly, if Indian coal were to remain the primary fuel, then capture technologies would have to be developed specifically for Indian coal conditions, e.g. high-ash content. This would entail a significant amount of in-house R&D, requiring support from the Indian Government. It should also be noted that coal is not uniformly distributed across India (Figure 5.3) and certain states would require more resources and fiscal support than others. The political and technical challenges associated with this particular pathway are discussed in further detail in Chapter Seven.

Alternatively, if India based its new fleet of power stations on imported coal, then it may be possible that capture technologies designed elsewhere could be transferred, for example, through an international joint venture. Meaning that CCS R&D could potentially take place outside India, designed to function on foreign coal, and therefore less involvement of the state in regards to technological innovation. However, there are strong political dimensions associated with this pathway, which can influence how CCS technology transfer occurs. For example, India's relationship with coal-rich nations will not only effect security of supply, but also influence the type of CCS technology adopted (see again Chapter 7).

Essentially, the type of fossil-fuel affects the design of the power plant required for electricity generation, and this in turn influences the type of CCS technology transfer pathway. Therefore, the power sector is also a crucial sector to consider in this context. Again, the technical intricacies of a potential CCS chain in India are discussed further in Chapter Seven, and the primary aim of the following sub-section is to give an overview of the present state of India's fleet of power plants.

5.3.2 India's Behemoth: The Power Sector

The previous section examined the limitations related to India's coal reserves affected the potential for CCS technology transfer: coal is the dominant fuel for India's power sector, and hence electricity generation is another crucial element of India's energy system. This section therefore presents the current state of the power sector and what the challenges and opportunities there were during the study period (2007-10) for CCS to be applied, in order to abate carbon emissions from electricity generation.

The power sector is the main driver for India's increased energy demand, where presently 70% of the country's total generation comes from thermal-based power plants, and this is unlikely to change for the foreseeable future. During the 10th Five Year Plan (2002-07), around 9 GW of new coal-based capacity was installed, and another 48GW of new capacity was outlined for the 11th plan (2007-12) (Planning Commission 2006). Figure 5.4 shows that most of the coal capacity has been added over the last 30 years, and gas capacity has increased in the 1990s. The addition of gas to the energy mix is a direct result of the economic reforms that were set in 1991, which liberalised the market (see Section 5.2.4), allowing industrial consumers to be less reliant on public supply of coal by building their own gas plants.

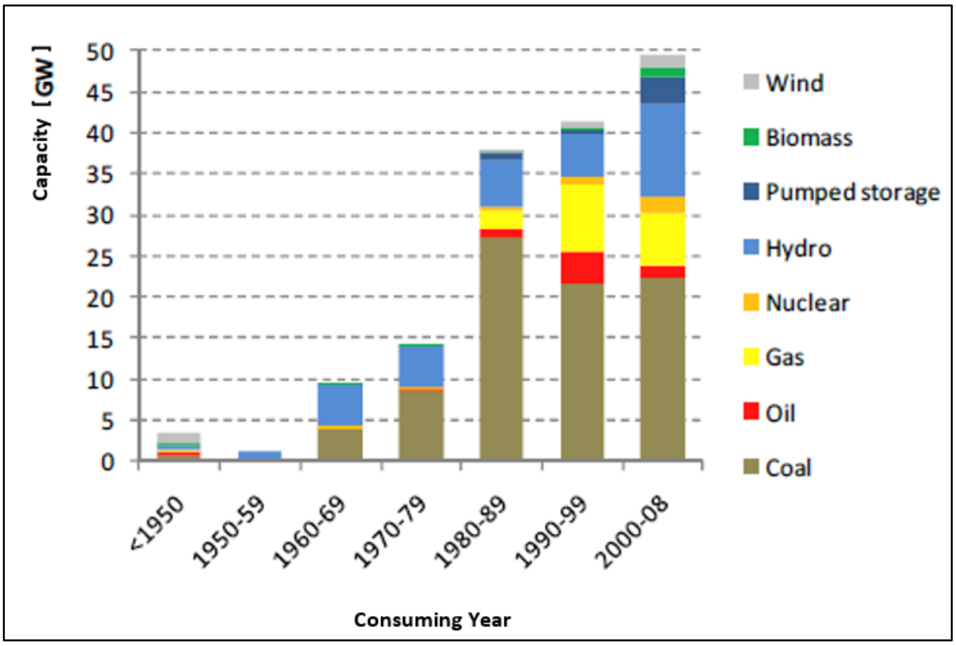

Figure 5.4: Age structure of India's existing power capacity (source: IEA 2011c).

According to the Central Electricity Authority (CEA), the total installed capacity in India by 31st March 2008 was 168GW, out of which 143GW (roughly 85%) was owned by utilities (CEA 2009). The breakdown of India's current installed capacity is illustrated in Figure 5.5, and due to load factors and the operation of plant, the installed capacity tends to be different from the actual electricity generated. Historically, the power sector has been predominantly under state control, though the Electricity Act of 2003 has opened up generation and distribution to the private sector (see Planning Commission 2006). This was mainly due to pressure from industrial consumers, who required a consistent and larger volume of electricity (Joseph 2010; Tankha 2010).

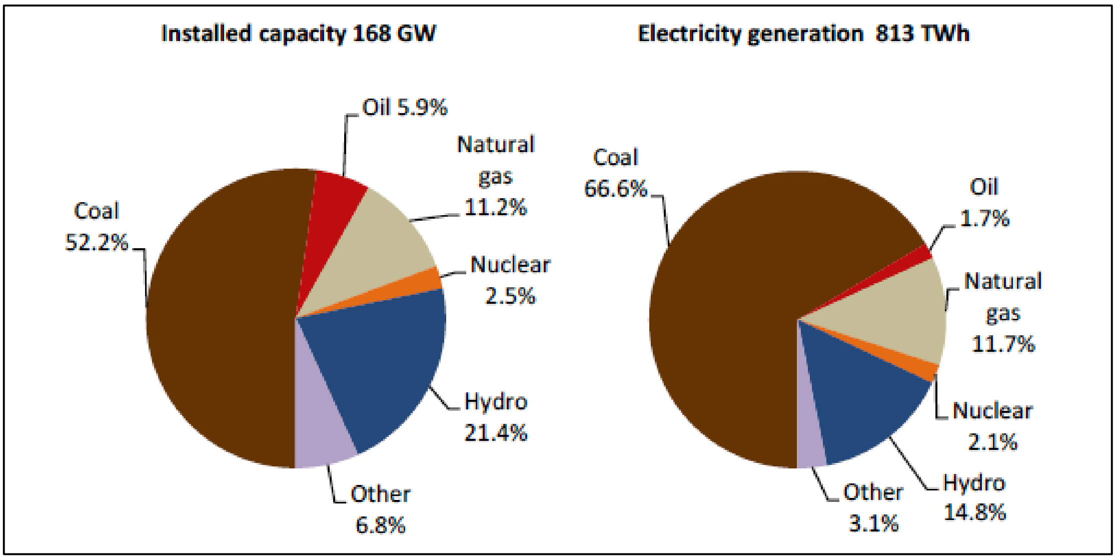

Figure 5.5: India's installed generation capacity and gross electricity generation (Fiscal year 1 April 2007- 31 March 2008) (source: IEA 2011c).

India's current operating fleet of coal-fired power plants is the third largest in the world, and, as is shown in Figure 5.6 below, where apart from the recent exception of a supercritical power plant, the power fleet is based on older and less efficient subcritical technology[60] (IEA 2012). Presently, the average net efficiency of India's entire coal-fired fleet is roughly 29%, where the more modern subcritical units (500MW) have an

[60] The efficiency of pulverized coal-fired power plant technologies is affected by the steam conditions, where the temperature and pressure is lower in subcritical plants, giving them a typical efficiency of 39%. In comparison, supercritical and ultra-supercritical technology allows for higher temperatures and pressure for its steam conditions, giving it a typical efficiency of 42% and 47% respectively (see IEA 2012, p. 11). It should also be noted that local conditions such as maintenance or operating regimes, would also have an influence on efficiency levels.

average of 33%, though some very old power plants are still in operation (Chikkatur et al. 2009). In comparison, the fifty most efficient coal-fired stations in the US have a net efficiency average of 36%, and the fleet's average is 32% (Chikkatur 2008). In terms of CCS applicability, the low efficiencies of current Indian power plants made it uneconomical to retrofit them with carbon capture technology. A survey respondent stated that "due to the age of the plants in India, their efficiency is about 35% and therefore not suitable for CCS, as 40% is recommended as a good figure for installing capture capability" (Respondent 9, Survey 2009, Appendix C). Therefore, only the newer power plants constructed would be able to meet the efficiency conditions suitable for CCS, and the potential of such plants is discussed in more detail in Chapter Seven. However it should also be noted that in regards to overall efficiency, CCS was also viewed by one stakeholder as contributing further to the problem of inefficiency, where "additional fossil fuel emissions, auxiliary power consumption, deterioration in efficiency of the generation and the cost involved in supplementing the generation due to the loss of efficiency" (Respondent 5, Survey 2009, Appendix C).

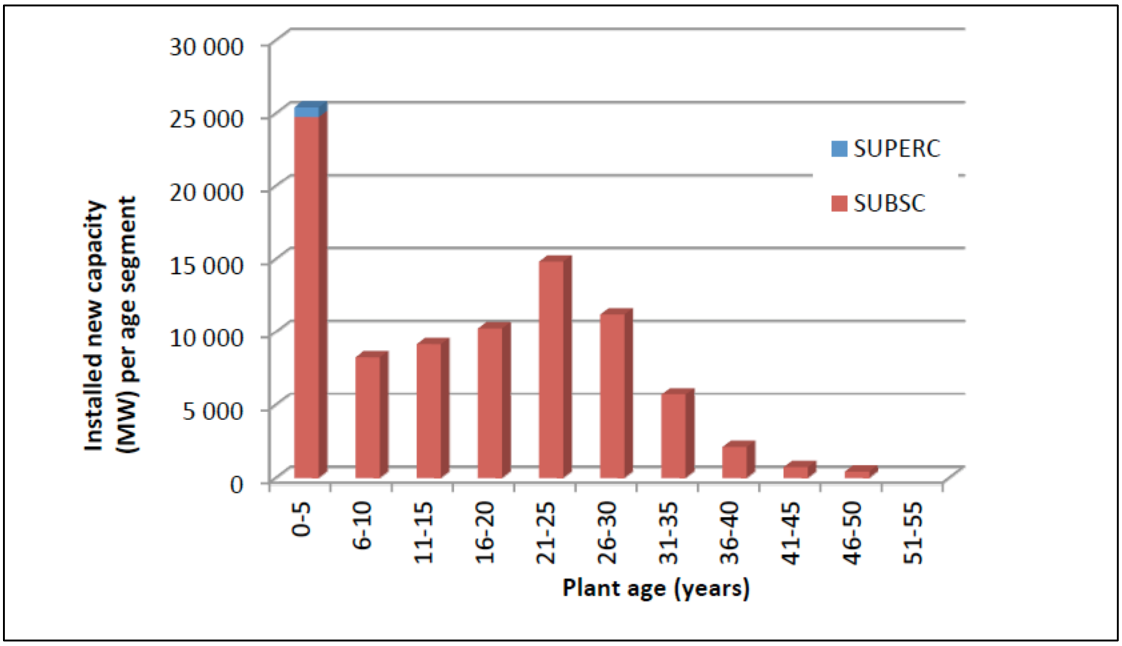

Figure 5.6: Age of current coal-fired operating fleet in India (supercritical (in blue) & subcritical (in red) power plants) (Source: IEA 2012).

One of the biggest factors that lead to the low efficiency of India's power plants is the quality of the coal. The poor quality is due to its very high ash content (roughly 30-

50%) (IEA 2002a: 103) and high moisture content, which varies between 4-20%, depending on the monsoon season (IEA 2002a: 26; Ghosh 2010). As a consequence, Indian coal has low calorific values (between 2500-5000 kcal/kg) (IEA 2002a), whereas the global average is roughly 6000 kcal/kg (Ghosh 2010). This lower calorific value of Indian coals implies more coal usage to deliver the same amount of electricity. On the other hand, Indian coal has very low sulphur content, approximately 0.2-0.7% (IEA 2002a: 103) in comparison to other coals; Ohio coal in the US has a sulphur content of 1.8% (Chikkatur 2008). Nevertheless, high-ash content can cause significant problems for operating a power plant, including high fly-ash emissions, ash disposal requirements, corrosion of boiler walls, and complications with coal washing[61] (IEA 2002a). Furthermore, the quality of Indian coal supplied to power plants has decreased since the 1970s, and over the past three decades the ash content is consistently 40-45% (Chikkatur 2008). This coincides with an increase in opencast mining (up to 300m) and production from inferior grades of coal, and is expected to dominate production for the next 20-30 years (Ministry of Coal 2006). Consequently, in 2008 the auxiliary consumption[62] of coal in India was an average of 8.3% of total gross power produced (CEA 2009), which is high in comparison to the average auxiliary consumption of 5.7% in European power plants the same year (IEA 2011c). Moreover, there is scope for bringing down this consumption by improving maintenance and management practices, especially in state-operated power plants (Chikkatur et al. 2009; IEA 2011c). This is an area where international technology transfer can play a useful role, though may be hindered by the significant state control of the sector.

[61] Coal washing removes ash and impurities from coal, leading to improved combustion and, therefore, higher power plant thermal efficiency. However, Indian coal has the general characteristics of Southern Hemisphere Gondwana coal, whose seams are inter-banded with mineral sediment (IEA 2002a). Consequently, the ash tends to be intermixed quite well into the coal structure itself, making the physical methods for coal washing even more difficult. The higher levels of alumina and silica in the ash can also increase ash resistivity, which can in turn increase emissions (Chikkatur 2008).

[62] 'Auxiliary consumption' of coal refers to the amount of fuel used to run the power plant itself. For example, auxiliary units are used to power machinery that is essential to move coal, air, combustion gases, and water through the process of electricity generation in the power plant (see p2-1 & 2-2, EPRI 2011). Auxiliaries influence the overall efficiency of the power plant, whereby the "sub-optimal operation of auxiliaries unduly increases heat rate resulting in what is essentially 'wasted electricity'." (EPRI 2011, p2-3).

A fundamental challenge to CCS technology transfer in India was identified as the high-ash content of Indian coal, which impacts plant efficiency: capture technology would need to be designed in such a manner as to accommodate the high-ash. Several stakeholders participating the research survey cautioned that CCS in India might not cope with the high-ash content of Indian coal, or whether it would require imported coal as its fuel base (Survey 2009, Appendix B). Over half the respondents (11/18) stressed that if India were to come closer to adopting the technology, then research specific to Indian coal conditions would be needed (*Ibid.*). Therefore, this demonstrates the need for India-specific CCS R&D. However, as discussed earlier, this will require support from the state, or a 'system builder' (see discussion on nuclear power in Section 5.2.2).

Another significant contributor to inefficiencies within the power sector is the state of the national power grid; India has some of the highest transmission and distribution losses in the world, which are difficult to quantify. In terms of technical and commercial factors, on average, losses of 32% of total electricity generation were reported by the CEA, with some states reporting losses as high as 50% (CEA 2009). Recent analysis by the IEA found that due to overloading of the distribution equipment during periods of peak load, electricity losses could exceed 45%, and therefore recommended designing systems with sufficient reserve (IEA 2011c). Moreover, there are also significant losses due to non-technical reasons such as theft and corruption, which are far more difficult to quantify. A high proportion of these losses come from the illegal tapping of lines as well as faulty electric meters that underestimate consumption, and therefore less payment is collected (IEA 2011c). In an interview with a security professional, it was mentioned that there are a significant number of cases of corruption at the State Electricity Board (SEB) level, where faulty electric meters remain unchecked on purpose, or bribes pass hands so that unpaid bills never get questioned (Interview B8, 2008). In addition, it was stated that there are many cases of illegal tapping of electricity lines, that are generally ignored, and were only considered a priority if deaths are an outcome (Interview B8, 2008). This interview findings are supported by the research of Golden & Min (2012), who examined theft and electricity loss in the state of Uttar Pradesh, India's most populous state. Their work concluded that power theft was significant and widespread, but not necessarily due to poor governance, but rather, aligned with local or state elections. Furthermore, a higher proportion of line losses occurred in agricultural areas, particularly to power privately owned tubewells, implying wealthy farmers, who already reap benefits of subsidized electricity from the government (Golden & Min 2012, p. 24). In addition, analysis by Joseph (2010) shows that in the state of Karnataka, nearly 40% of the electricity supplied goes unmetered, so theft is likely to account for more than what is recorded by the state.

The issues discussed above had relevance to the potential for CCS technology transfer in the period under study (2007-10). This is because local politics and irregularities within the system, such as theft and corruption, were identified as discouraging foreign investment (Interview B5 2008; Interview C1 2008; Interview C3 2008). In the context of CCS, transmission and distribution is a key part of the energy system, and the upgrade and development required in order to accommodate new-build power stations on the grid was a factor in consideration of CCS. Such security concerns over India's energy sector and their impact on potential technology transfer are returned to in Chapter Seven.

Recently, the Indian government has been putting in more effort to attract FDI and joint ventures to the Indian power sector, and during the past five years, Chinese manufacturing companies have entered the market. Notably, the Shanghai Electric Group is the main supplier for India's first supercritical power plant, the Mundra power station in Gujarat, constructed by Adani Power Ltd. in 2010. Furthermore, this particular project is eligible for Certified Emission Reduction credits (CERs) under the United Nations Framework Convention on Climate Change (UNFCCC), and its crediting period under the Clean Development Mechanism (CDM) runs from 2008 to 2018 (UNFCCC 2010). Even though Chinese products are cheaper and becoming more readily available, India's domestic manufacturers, Bharat Heavy Electricals Limited (BHEL), has stated that 'a number of Indian power companies were moving away from Chinese products because they were of inferior quality' (Ebinger 2011, p. 140). Consequently, the CEA has started pushing for more supercritical and ultra-supercritical technologies, where, in 2010 a letter was sent to encourage every state-run power company to rely on domestic manufacturers for super-critical power plant equipment (Ebinger 2011, p. 140). More recently, the Indian Government has unveiled plans to impose duties of roughly 20% on imported power equipment (Economic Times 2012a), with further calls to impose duties specifically on equipment for mega and ultra-mega power plant projects greater than 1000 MW (Economic Times 2012b).

By 2030, the Indian Government's Planning Commission anticipates the installed capacity of coal-based power plants to be within 200 to 400 GW, including the Ultra-Mega Power Plants (UMPPs)[63] that are expected to come online post 2012 (Planning Commission 2006). According to the government's Power Finance Corporation, the total number of UMPPs envisaged is sixteen, out if which four contracts have been already been awarded (Interview B10, 2008). Given this rate of expansion of the power sector in the next 20 years, it is likely that the majority of the currently estimated extractable coal will be utilised over the course of the 40-50 year lifespan of power plants (Chikkatur et al. 2009). Therefore, key strands of India's draft energy strategy for the 12th five-year Plan (2012-2017) include developing in situ gasification to tap coal resources difficult to mine through conventional technology, as well as increasing coal production through competition and building further coal import facilities (Planning Commission 2011). Furthermore, a reduction in demand of domestic coal could be achieved by increasing the costs for consumers, but this will impede on India's development ambitions as well as national energy security concerns. The 12th five-year plan has also indicated an interest in Integrated Gasification Combined Cycle (IGCC) technology, as well as stating:

> *"Development in technology for Carbon Capture and Storage (CCS) needs to be carefully monitored to assess the suitability and cost effectiveness of this technology for Indian conditions."*
> *(Planning Commission 2011, p. 42)*

In addition, the government is keen to diversify into cleaner fuels for power generation, where the energy security brief 'Hydrocarbon Vision 2025', issued by the Ministry of Petroleum and Natural Gas, calls for an expansion into electricity generation from natural gas because it is cleaner and more efficient than coal or oil (Ministry of Petroleum & Natural Gas 2001).

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[63] UMPP has a power generating capacity of 4GW per site and will use supercritical technolgy.

The newer power plants discussed above are an area where there is strong potential for CCS technology transfer, and this is discussed in greater detail in Chapter Seven. The UMPPs based on imported coal would cut down the technical challenges associated with high-ash coal, in addition to being a more efficient plant in overall maintenance and operations. Given the Indian Government's keenness to upgrade its power fleet, there is potential for an increase in international collaboration and knowledge exchange. Similarly, there is potential to adapt newer gas-fired plants with CCS technology, which is currently being explored by the US and UK (GCCSI 2011). However, during the study period (2007-10) there was a lack of political will to support CCS implementation in India. India's reforms for improved efficiency in power plants during this period were not only a start for cutting carbon emissions, but they also created favourable technical conditions for potential CCS implementation. Nevertheless, despite such conditions, during the study period, for social and political reasons, the Indian Government did not favour implementing CCS with the new fleet of power stations. These aspects are discussed further in Chapters Six and Seven.

5.3.3 India's Large-Scale Industries

Private industries are now beginning to play a role within India's energy system, and their newer efficient power plants were also considered as an alternative route for CCS technology transfer by some Multi-National Corporations (MNCs) during the study period (2007-10). Regardless of the inefficiencies and inconsistencies in the power sector, India's large-scale industries remain a key consumer of electricity, where over 40% of the electricity generated in India went to the industrial sector in 2007 (see Figure 5.7). However, a growing trend in many industries is to install their own power plants, known as 'captive power plants,' in order to ensure consistent quality and supply of power to meet their requirements. Of the 25GW of captive power plants, most of these were fuelled by coal (47.1%), diesel (34.6%) and natural gas (16.8%) (CEA 2009).

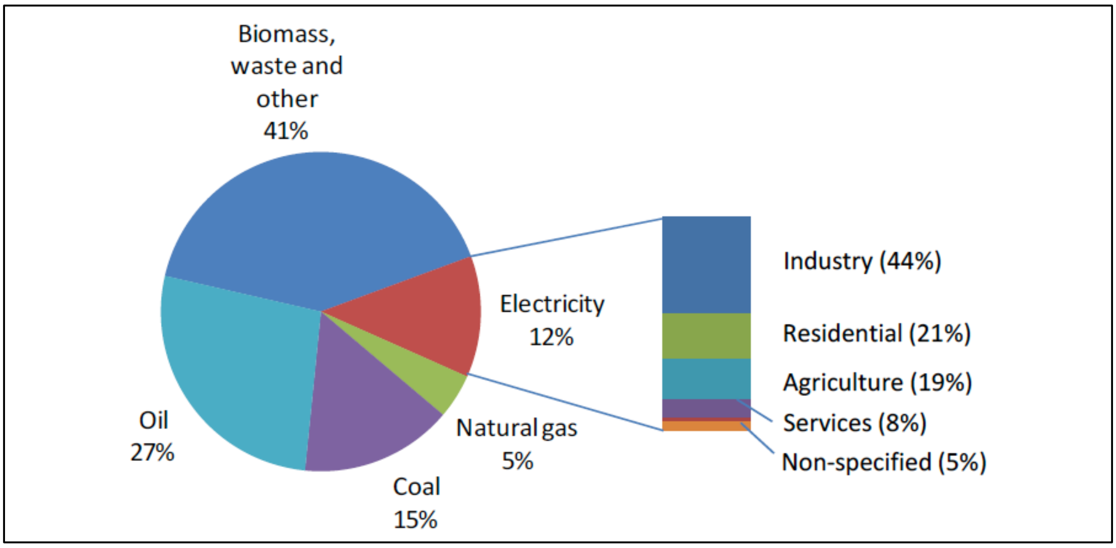

Figure 5.7: Total final energy consumption in India in 2007 (394 Mtoe) (source: IEA 2011c).

Moreover, the government is actually encouraging industry to build captive plants, as a means for bringing in reform to the power sector. The Electricity Act of 2003 contains an open access clause, which takes away the authority of the State Electricity Boards (SEBs) to veto the transmission of electricity through their lines, allowing any surplus electricity generated by captive power plants to be sold to the grid (see Planning Commission 2006). Analysis by Joseph (2010) indicates that an increase in captive plants and the sale of their surplus power, has given rise to "a parallel economy alongside the state-run electricity sector", where roughly 20% of India's installed capacity comes from captive power (Joseph 2010, p509). This has allowed politicians to invigorate private sector participation, whilst maintaining the support of key political constituencies at the state level (Joseph 2010).

The key industries in India are iron and steel, aluminium, cement, chemicals and petrochemicals, and they provide various inputs to other sectors such as power transmission, construction and transportation (Dutta & Mukherjee 2010; IEA 2011b). The increase in production in India's large-scale industries is a direct result of the reforms and liberalisation in the 1990s (Dutta & Mukherjee 2010). Some of these industries are not only essential for developing the country's own infrastructure, but they also contribute significantly to the national and global economy through exports. India is rich in iron ore and bauxite (the raw material for aluminium) and the largest demand for metals comes from China, though recently Japan has become an important customer, and 5.87 Mt of iron ore was bought for re-construction after the Fukushima earthquake in 2010, and the demand for finished steel products is likely to increase in the coming years for many economies in transition (Bhattacharya & Roy 2011). The breakdown of India's main exports for the fiscal year of 2007/08 is shown in Figure 5.8.

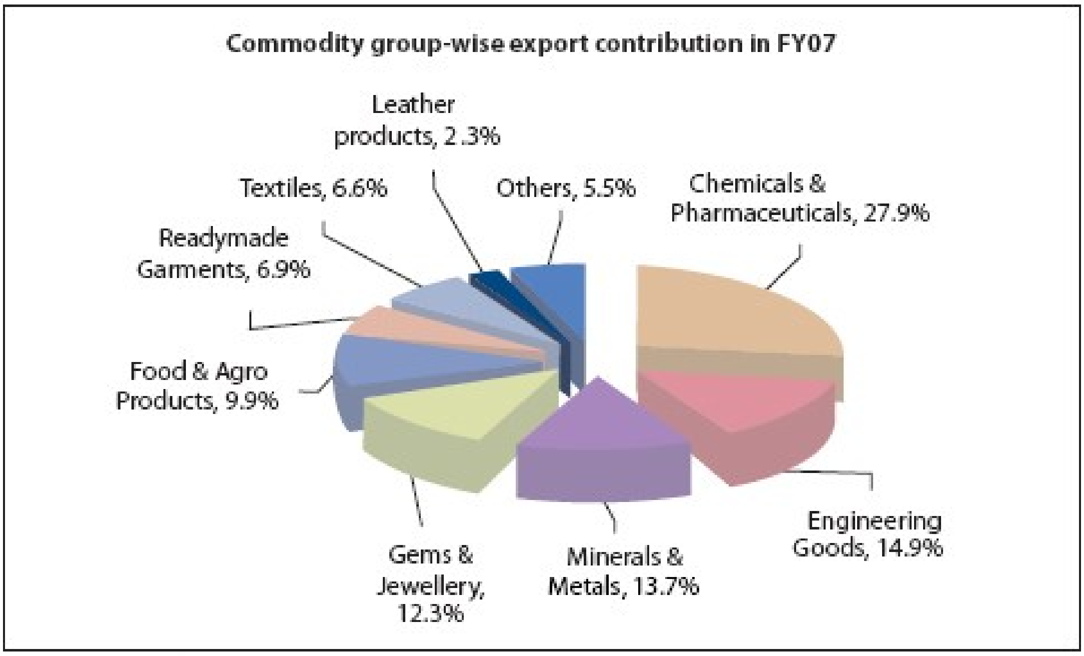

Figure 5.8: India's main exports for the fiscal year 2007 (source: Dun & Bradstreet Information Services Pvt. Ltd. (http://www.dnb.co.in).

Even though India has limited oil resources, it has developed a very robust refining and petrochemical sector, and has the largest refining capacity in Asia. The world's biggest oil refinery is in Jamnagar, in India's western state of Gujarat, which has a capacity of 1.24 million barrels per day, and it is owned by Reliance Industries (Ambani family) (Ebinger 2011). There are also another 25 refineries across the country (BP 2012). The refining of petroleum products is a key part of India's export strategy, and also a crucial industry for many countries that have the resources, but may not have the facilities to process them. For example, India was the third largest market for Iranian crude in 2009/10, and at the same time its main exports to Iran included, *inter alia*, refined petroleum products and petrochemicals (Ministry of External Affairs 2012). India is expected to emerge as Asia's largest exporter of refined petroleum products by the end of 2012 (Ebinger 2011; BP 2012).

The variety of industries discussed above all have the potential to integrate CCS into their systems if there is a strong incentive to cut carbon emissions. There is potential to capture carbon emissions from captive power stations, as these plants are likely to be newer and efficient build, but also they would be subject to less state control. However, a survey respondent pointed out that:

> *"Private power generators such as Reliance have little incentive to be involved in CCS since they have no influence over pricing of electricity. The central and state governments decide the tariff structure for electricity. This implies that the private players have no way of increasing the tariff, especially if they implement CCS and pass on the cost to the consumer" (Respondent 5, Survey 2009, Appendix C).*

In addition, it was commented further "the private sector (non-PSU companies) will play a much smaller role in low carbon technologies than the Government and PSUs"[64] (*Ibid.*). Overall, majority of survey respondents felt that CCS would not be an investment priority for the private sector industry in India due to its links with large Government controlled sectors such as electricity transmission and distribution (Survey 2009, Appendix B). Survey results indicated that the top ranked technologies for private industry investment were mostly renewables (solar, wind, hydro and microgen) (*Ibid.*).

Nevertheless, CCS does not necessarily have to be applied to electricity generation. As discussed in Chapter Four, there is potential to capture CO_2 emissions from other industries such as, cement production and refineries. However, the forthcoming chapters in particular demonstrate the challenges associated with CCS technology transfer to India. For example, Chapter Six illustrates the clear lack of political will to consider CCS in India, and how the position of the Indian Government prevented any technology transfer during the period under study. Moreover, CO_2 capture is only one element of the CCS sociotechnical system (see Chapter 4), and this section has largely

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[64] PSU stands for Public Sector Undertakings. This is a term commonly used in India for a government-owned corporation (company in the public sector). The term is used to refer to companies in which the government (union, state, territorial or both) owns a majority (51%) of the company equity.

considered India's energy context in terms of capturing the major sources of emissions. In order to fulfil the purpose of CCS, these emissions will not only need to be captured, but also safely transported and permanently stored deep in the subsurface. Therefore, the feasibility of the full CCS technology chain in an Indian context is considered in detail in Chapter Seven.

5.4 Summary and Conclusions

This chapter highlights the complexities of the Indian energy sector, not only by examining the current fuel mix and infrastructure, but by also exploring the historical influences on the establishment of this large sociotechnical system. One of the insights from this review is that India is already locked-into a carbon-intense energy system and there is potential for CCS to play a role in decarbonisation of the sector. Since the time of India's inception, coal has been a dominant feature in India's energy mix, especially for power generation, and will remain so for the foreseeable future. Fossil fuels are also the principal source of energy for India's industries, including the energy intensive sectors of steel and cement production. Given the flexibility and multiple identities currently associated with CCS technologies, there are potentially a number of areas, namely power generation and large-scale industries, where CCS technologies could be applied in order to cut CO_2 emissions.

Furthermore, India demonstrates an historical tradition for innovation as well as participation in international technology transfer. Science and technology development played a crucial role in India's struggle for freedom and the foundations for its NSI, which developed shortly after independence, is a source of pride for the Indian people. India demonstrated its capacity for indigenous innovation and R&D through its nuclear power programme. However, at the same time, other key energy sectors were neglected, notably, India's coal based energy system, which was inherited from British colonisation. This particular aspect of India's energy sector became more and more nationalised over time, which created state monopolies over the coal and power sectors, preventing any reforms. Consequently, India is presently locked into a highly regulated energy sector, which is heavily dependent on coal, and relies upon an inefficient fleet of power stations. This aspect of India's existing energy sector posed a challenge for CCS implementation, requiring not only state support, but also concentrating almost exclusively on new-build power stations.

Although post-independence is a period marked by stagnancy and meagre resources, even so, it brought out India's unique innovation style, or *Jugaad*. This entails more of an improvised 'quick-fix', which can support the SMEs predominant in the IT sector, but not large technological systems, such as CCS. Nevertheless, India's history with nuclear energy demonstrates that through international technology transfer and local R&D, it is possible to establish and manage an energy-related sociotechnical system. However, survey findings strongly indicated that nuclear is seen as a higher investment priority for the Indian Government than CCS. Moreover, Box 5.1 illustrates the importance of state support, political drivers and international relations for such technology transfer to occur. Political will, both in the domestic context and in terms of international linkages is crucial for CCS implementation, particularly at the state-level, but has not been strong enough in the period 2007-2010. These aspects are further explored in Chapter Six and Seven.

Energy demand outstrips supply, where power outages and unreliability of electricity supplies further impede India's economic development. One of the challenges of implementing CCS has been the uncertainty associated with Indian coal reserves, and therefore imported coal is becoming more reliable, particularly for large industries, which are also opting more for captive power plants. Further technical challenges to CCS technology transfer have been India's poor quality of coal, due to high-ash content, hence relying on imports. In addition, India currently relies on an aging and inefficient energy infrastructure, including a fleet of power stations based on old technology. These, along with electricity transmission and distribution systems, required substantial upgrades in order to support any CCS deployment. These factors acted against prospective CCS implementation in India. Also, there were additional non-technical issues, such as security concerns over electricity theft and corruption, which contributed to the significant overall losses (i.e. technical and commercial losses) from the energy system, which also disadvantaged CCS. The following two empirical chapters explore the feasibility of CCS technology transfer to India in 2007-2010 in more detail; Chapter Six through the international lens and Chapter Seven focuses on the domestic situation. The aim is to analyse in more detail the specific sociotechnical challenges in India that have obstructed the introduction of CCS technology, building upon the findings of this chapter.

Chapter 6: Feasibility of CCS in India – International Context

6.1 Introduction

The period under study for this thesis was from October 2007 through to August 2010. During this period CCS was a prominent feature of international discourse on climate change mitigation. This period was also important for Indian engagement internationally on CCS research and development (R&D). It included two specialist and high-level meetings between the European Commission and Indian Government representatives from relevant energy sectors, both held in New Delhi, one in January and one in November 2008. In addition, the UK government hosted a technical CCS workshop and the Norwegian Government were the chief sponsors of the 2008 Delhi Sustainable Development Summit (DSDS).

In parallel, during this period CCS technology was also of strong interest in the broader climate policy debate, notably the international climate negotiations. Therefore, this chapter on the international context of CCS technology transfer is split into two core sections: Section 6.2 examines India's international position on climate change, and how this in turn influenced its international engagements, specifically on CCS; and Section 6.3 considers the overall debate in the UNFCCC forum, specifically the dialogue under the CDM workstream.

This chapter draws upon data gathered first-hand in field notes collected at each of these events, where the author was a participant observer. Table 3.1 (Chapter 3, p. 70) gives a summary of the relevant field activities, and details of the interviews that are used to provide insights for this chapter can be found in Table 3.2 (Chapter 3, p. 72-75).

As discussions in previous chapters have shown, CCS is a complex, multi-dimensional technology – best characterised as a sociotechnical system rather than a discrete technology – with strong international political dimensions to its innovation, development and subsequent transfer. Moreover, complexities associated with its mixed identity makes CCS technology transfer a multifaceted and highly political process between states, and international relations and good diplomacy have an imperative role. Therefore, a sociotechnical perspective is used to explain India's reluctance to embrace CCS technology. In addition, the broader international context of CCS technology transfer is explored, highlighting the key drivers behind the initiative. Since the domestic and international context are inherently overlapping, there are connections between this chapter and Chapter Seven which deals with the domestic context. The Cambay Basin case study (see Chapter 7) explores further the linkages between the domestic and international context.

6.2 India's Position: Common but Differentiated Responsibility

The clues for understanding India's official position on CCS technology can be found within its domestic environmental policies, and by examining its broader approach to climate change. For example, some of the key elements of the National Environmental Policy 2006 include the priority and right to development, as well as strict abidance to the principle of Common But Differentiated Responsibilities (CBDR) (Government of India 2006). In this context, CBDR refers to Principle 7 of the Rio Declaration (1992) and it is an important aspect of international environmental law, thereby connecting equity and justice with environmental conservation (see Birnie et al. 2009; Cullet 2010). Moreover, within the international domain "issues of justice are largely structured around states", especially the relationship between developed and developing nations (Cullet 2010, p. 162). Therefore, the notion of CBRD can be described as follows:

> *"Although responsibility is common to all states, developed and developing alike, higher standards of conduct are explicitly set for developed states on the grounds that they have both contributed most to causing problems such as ozone depletion and climate change and that they also possess greater capacity to respond than is generally available to developing states." (Birnie et al. 2009, p. 133)*

It is this principle of global environmental responsibility that lies at the heart of India's stance in the broader international discourse regarding climate change mitigation and adaptation. India is an active contributor in international climate negotiations; it is a party to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, in addition to being a member of the Asia Pacific Partnership on Clean Development and Climate, an initiative that involves the

US[65]. Rajamani (2008, p. 422) points out that within these international fora India has maintained a consistent stance, arguing that "given its limited role in contributing to the problem thus far, its overriding development needs, and the historical responsibility of industrialised countries, India cannot be expected to take on mitigation commitments." The significance of this position is the coupling of development objectives and addressing climate change. Therefore, the key question for India during the period of study was: how does CCS technology contribute to sustainable development? This question was also raised extensively by other developing countries in the climate negotiations, as the concept of CBRD is also a central element of the "burden-sharing architecture" of the UNFCCC and its Protocol (Rajamani 2008, p. 425) and this is discussed in more detail below (section 6.3).

India's international stance involves the twinning of development and climate goals, and is best understood by examining India's domestic policies. India's overall approach to GHG mitigation is based on the 'logic of co-benefits' (Rajamani 2009). In the context of climate mitigation policies, the term 'co-benefits' refers to other non-climate benefits, such as sustainable development, and is defined by the IPCC as follows:

> *"The benefits of policies implemented for various reasons at the same time, acknowledging that most policies designed to address greenhouse gas mitigation have other, often at least equally important, rationales (e.g. related to objectives of development, sustainability, and equity)." (IPCC 2007c, p. 98)*

This concept derives from the principle of CBRD, and forms the central ethos of India's National Action Plan on Climate Change (NAPCC), which was launched in 2008. It is an approach whereby climate change measures will only be taken that also promote development objectives, i.e. which simultaneously yield "co-benefits for addressing climate change effectively" (Government of India 2008, p. 2). This is because the Indian Government is "convinced that the principle of equity that must underlie the global approach must allow each inhabitant of the earth an equal entitlement to the

[65] This is important because the USA is not a signatory to the Kyoto Protocol.

global atmospheric resource" (*Ibid.*). The NAPCC goes on further to state that "India is determined that its per capita greenhouse gas emissions will at no point exceed that of developed countries even as we pursue our development objectives" (*Ibid.*). Hence, this is the official stance that India has maintained throughout the international negotiations on climate change, and Rajamani (2008, p. 425) notes that India's position is arguably legitimate, though "not a sagacious one". This is because, as discussed in Chapter One, India is likely to be one of the most vulnerable to the effects of climate change, even though it has contributed little to causing it (see Section 1.2). Nevertheless, it helps explain why India has been reluctant to take on any large-scale mitigation commitments, such as CCS. It also helps explain aspects of the international politics regarding climate change and India, as demonstrated by the following comment made by a respondent to the stakeholder survey in regards to energy and climate change mitigation:

> *"India is not under Kyoto obligation to cap emissions, yet it is on course to have 40% clean electricity by 2020 [as envisioned by the NAPCC]. Yet there is a lot of propaganda in the western press, clubbing India with China about growth of emission. Most developed countries have failed to achieve their Kyoto targets; the US has not even ratified the Kyoto treaty. To expect anything more from India is unjust." (Respondent 16, Survey 2009, Appendix C)*

Linked to this perception of receiving unwarranted pressure from the developed world regarding its emissions, India deliberately chose to distance itself from CCS-related dialogue in the UNFCCC forum, and this is analysed in further detail below. Here the implications of India's position within the climate negotiations and its impact on how CCS technology is perceived by India, is discussed in the following subsections, which analyse international engagement activities on CCS research and technology transfer. This analysis draws upon data gathered during the two fieldwork trips made to India in 2008 (see Table 3.1).

6.2.1 India's International Engagement on CCS Activities

In 2005, India was a key participant in the G8 + 5 dialogue at Gleneagles, where CCS technology was specifically promoted as a crucial element of the G8 Gleneagles Plan of Action on Climate Change, Clean Energy, and Sustainable Development (UK DECC 2005,

p. 5), developed at the first Ministerial-level meeting in July 2005. Notably, the aim of the meeting was to “accelerate the development and commercialisation of Carbon Capture and Storage technology by… working with industry and with national and international research programmes and partnerships to explore the potential of CCS technologies, including with developing countries” (*Ibid.*). One of the strategic partnerships highlighted in the Gleneagles Communiqué was with the Carbon Sequestration Leadership Forum (CSLF), which was founded by the US in 2003[66]. Subsequently, India signed a pact with the US in 2006 on the FutureGen project and related CSLF research activities (PTI 2006). The CSLF endorses research in India that focuses on the storage potential of basalt formations, which underlie much of the subcontinent (see Chapter 7, Section 7.2.3). Another key outcome of the Gleneagles Summit was the setting-up of clean coal workstreams by the European Commission, in order to “support programmes and external elements such as technology cooperation with key countries on CCS” (Fujiwara & Egenhoffer 2008, p. 36). A direct result of the Gleneagles dialogue was also a series of international workshops held in India on CCS and R&D challenges, starting with two held at the National Geophysical Research Institute, Hyderabad in 2006 and 2007[67].

The workshops that followed shortly after, in 2008, form the basis of fieldwork activity for this thesis (see Table 3.1), and these events are the primary source of data, gathered either through participant observation or through one-to-one interviews with elite stakeholders, present at these events. In addition, on the basis of these workshops, a network of key stakeholders was created who were then surveyed in order to elicit further opinions on the prospects of CCS technology in India (see Chapter 3; Appendix A, B & C).

However, despite India’s participation in these meetings and CCS research initiatives, India’s Government position on CCS in the period 2007-10 can be

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[66] The Carbon Sequestration Leadership Forum (CSLF) is a Ministerial-level international climate change initiative that is focused on the development of improved cost-effective CCS technologies. It is comprised of 22 member states and the EU Commission (see: http://www.cslforum.org).

[67] An outcome of this international dialogue has been the establishment of the Indian CO_2 Sequestration Applied Research (ICOSAR) network by the Dept. of Science and Technology.

characterised as one of reluctance, particularly within the UNFCCC discourse regarding the Clean Development Mechanism (CDM). Issues regarding CCS within the CDM are discussed in detail below (section 6.3), however they are introduced here to give a sense of the tone and content of discussions, based on my participant observation fieldwork. The UK and EU sponsored events attended in New Delhi were controversial, given the Indian Government's position on CCS, as I observed at the time:

> It would seem that India has been avoiding any association with CCS in the international climate negotiations. Indian negotiators have been very outspoken about their reservations regarding CCS as a mitigation option under the CDM at previous COP/MOPs and CSLF meetings. A representative from the EU believes that this is because if the option were available under the CDM, then India might be in the position where they actually would have to clean up their heavily polluting coal-fired energy sector.
>
> DEFRA considered it a major concession by the Indian Government to give them permission to host the workshop; UK High Commission even surprised that Indian Government sent someone so senior (Minister for Science & Technology) to launch the event (Field notes, DEFRA/IRADe Workshop, New Delhi, 22 January 2008)

No sooner had the Minister taken the stage at the inauguration of the DEFRA workshop, he made it clear that the Indian Government was sceptical about CCS technology; he strongly emphasised that it was something for the 'far future' and, that any consideration of deployment or demonstration in India at this stage was 'premature' (field notes, DEFRA/IRADe Workshop, New Delhi, 22 January 2008). The reasoning he gave was that applying CCS was very expensive and the efficiency of power plants is reduced, factors which were 'not reconcilable with Indian priorities' (*Ibid.*). The Executive Director for Energy Technologies at the National Thermal Power Corporation Ltd. (NTPC), Dr. R Sonde, presented a similar case in the EU-India Working Group on Clean Coal. He said the reasons for not considering CCS at this time were primarily due to the high costs involved and ambiguities related with the environmental safety of CO_2 storage (field notes, EU-India Clean Coal Working Group, New Delhi, 21st January 2008). He also noted that India's current power fleet is already relatively inefficient (see Chapter 5); he was of the opinion that it was uneconomical to retrofit old power stations (their efficiency approx. 35%) with equipment that would reduce their efficiency even further (field notes, EU-India Clean Coal Working Group, New Delhi, 21st January 2008). However, he also stated that the Indian Government were not averse to research and collaboration, as they considered CCS a technology of the future, and a great deal more R&D was seen as needed on Indian specific conditions, especially on its high-ash coal (see Chapters 5 & 7 for detailed discussion of India-specific conditions). This became apparent at the DEFRA/IRADe workshop, where, once the Government officials left the proceedings, the research community consisting of nearly 100 scientists and engineers showed great interest and enthusiasm for CCS (field notes, New Delhi, 23 January 2014). CCS research was also at the time supported in India's domestic policies as an important option for the distant future, such as the Integrated Energy Policy (2006) (Planning Commission 2006, p. 105; Planning Commission 2011, p. 42).

India had an international stance of strong aversion to CCS technology. So it is clear that in the period 2007-10 the developed world (especially the UK and EU) was insistent that India take CCS seriously at this stage, given that CCS was at the time still at a nascent development stage, and yet to be deployed commercially (Rajamani 2011). India was deliberately cautious on CCS in the international domain in 2007-10 for two key reasons. First, because of CCS technology's mixed identity and how it was presented as a complete product with exclusively GHG mitigation objectives: the Indian Government has rejected this interpretation. The second reason is political, and can best be explained through a political realist lens, as within international fora state actors are known to act in self-interest, paradoxical to climate and environmental objectives that are seen as a 'common concern' in international environmental law (see Birnie et al. 2009, p. 128). The following section expands on these two explanations further.

6.2.2 "CCS isn't the right technology for India, so stop trying to sell it to us"

Using a sociotechnical perspective, the rationale behind India's reluctance to accept CCS, despite being encouraged by the international community, can be explained through two factors. First, building on discussions from Chapter 2 and 4, the CCS technological system being presented to India was designed to look like a coherent, discrete technology, (rather than a messy, complex system), which had the sole purpose of mitigating CO_2 emissions. The technology being promoted specifically was

CO_2 capture linked to coal, as coal-based power is the most CO_2-intensive energy sector. However, the chief aim of CCS was presented as curbing emissions, i.e. as a benefit is to the global commons; India's development objectives of poverty reduction and electricity for the poor were not seen as served by this aim. There was no co-benefit associated with CCS technology, which would satisfy India's approach to climate change and central ethos of CBRD (Rajamani 2011). CCS as defined by industrialised nations at the time did not fit with India's vision of climate mitigation: CCS was not viewed by India as contributing to sustainable development, which is equally, if not more, important to India, than mitigating climate change. Moreover, several Indian researchers felt that the permanent storage of CO_2 seemed like the waste of a good resource (field notes below). This is a viewpoint that had not been considered by international CCS proponents. The following is an excerpt of field notes from the Delhi Sustainable Development Summit (DSDS), which took place shortly after the EU and UK CCS workshops in 2008. It should be noted that the DSDS was initiated and organised by Dr. R. K. Pachauri, then the Chairman of the IPCC, and the overall theme of the summit was 'Sustainable Development and Climate Change.'

> Questions are being asked of how to '<u>use</u>' the CO_2; going to all that expense and effort, just to keep it stored underground makes no sense to some delegates. There seems to be more interest in concepts that involve using the CO_2 for something else, such as making building materials; similar to the way coal ash from power stations is currently used in the Indian cement industry.
>
> Engineer from IIT Delhi comments that CCS "does not seem innovative or, that cutting-edge enough" to get India interested. He also adds that, having looked closely at proposed CCS technologies, it seems as if "they are trying to sell old technology as something new"; other related comments made: "we know how to do EOR, so then just say that it is EOR, rather than trying to sell it as something else" (Field notes, DSDS, 9th February 2008).

From the various discussions with stakeholders that had attended both the DEFRA workshop and DSDS, it was apparent that CCS's uncertain and mixed identities posed a problem. If the CO_2 could be put to use for something then that would have made the CCS strategy more appealing to India (Interview A2 2008; Interview B6 2008). The premise of potentially using the captured CO_2 for Enhanced Oil Recovery (EOR) was also not well received. A senior representative from the Planning Commission commented that although this may be a method to cover the expense of the technology, it did nothing to bring electricity to the millions of rural poor, rather, it just increased profits for private companies operating project (Interview B6 2008). Furthermore, there was scepticism of the storage aspect of the CCS chain, particularly as capturing such large volumes of CO_2 and then storing it underground had yet to be demonstrated anywhere else in the world (Interview B6 2008), also:

> The Chairman of the Planning Commission lead a discussion at DSDS on India's long-term vision (2050) for addressing climate change. I asked a question regarding the suitability of CCS in the near-future and, he answered that the technology was not ready to be tried out in India now, despite the urgency to mitigate emissions by the global community. Adding that, if it worked in other parts of the world then could also be applied in India by 2050. His reservations were to do with safety; explained in an interview later: "We don't want another Bhopal disaster on our hands. What if something went wrong with the storage? How do we know that there won't be explosions of CO_2? [The] liability will be on our heads, not the private company [that builds the plant]. India is not prepared to be the guinea pig" (Combined field notes, DSDS, 8th February & interview notes, 27 February, Interview B6 2008).

One of the counter arguments used by EU delegates, deployed to convince India to get involved in CCS at such an early stage, was to do with Intellectual Property Rights (IPR) (Field notes, EU-India Clean Coal workshop, New Delhi, 21 January 2008). IPR issues related with technology transfer, especially from developed to developing countries, have been a contentious issue within the UNFCCC dialogue (see Ockwell et al. 2010; Srinivas 2012). NGOs participating at DSDS, such as Greenpeace International and the Centre for Science and Environment (CSE) were of the opinion that CCS was a commercial scheme that favoured large multinational corporations (MNCs), because the IPR belonged to them (field notes, DSDS, 8th February 2008). A representative from DFID said there was a lot of mistrust in this area, but efforts were being made to encourage more collaborative joint ventures (Interview B11 2008). The interviewee further explained how the issue of technology appropriateness had tainted the technology transfer process in the past, where India had been sold 'unsuitable technology'. In the context of energy technology transfer, the interviewee observed that in the past, organisations such as the World Bank had imposed certain prerequisites before granting loans. This included the precondition to open up the Indian power market to international equipment suppliers and implementing technologies that, in some cases, were not suitable to Indian coal (Interview B11 2008). This sentiment was also repeated in the stakeholder survey:

> *"There has been very limited financing and technology transfer from developed to developing countries. Also the technologies being given are not necessarily those which developing countries are currently comfortable with at the moment."* (Respondent 11, Survey 2009, Appendix B)

The issue of IPR is inherently linked to CCS technology's mixed identity, as CCS contains established technologies that already have existing patents associated with them. For example, patents for the composition of the amine solution needed to capture CO_2 reside with the company that has invested in the R&D to develop the technology in the first place, and is not owned by states. However, the negotiations regarding IPR in this context have largely taken place between states. Similarly, the IPR impediment to technology transfer is not just about patents; for the case of CCS, there is also an issue regarding '*trade secrets*', or processes essentially belonging to the company, the disclosure of which would harm the business' interests (see Martin & Law 2006; Sajewycz 2011). Trade secrets are quite prevalent in the oil and gas industry; examples include CO_2 injection techniques for EOR, seismic data and interpretation, as well as exploratory methods and geological maps. An industry stakeholder surveyed explained: "technology transfer is a difficult issue due to the corporate structure of many private energy companies and equipment suppliers, especially when met by large nationalised companies" (Respondent 5, Survey 2009, Appendix B). Moreover, CCS was perceived as an amalgamation of existing technologies, but also as something untested, giving it a mixed identity. The impact of this mixed sociotechnical identity on IPR issues specific to CCS are discussed further in the Cambay basin study in Chapter Seven.

The second factor influencing India's position on CCS has to do with politics, where the state is the chief actor, being the customer, regulator and underwriter (see Street 1992 & discussion in Chapter 2). The 2008 workshops attended in New Delhi specifically hinged upon India's bilateral relationships with the UK and Europe. For example, both the EU-Coal and DEFRA workshops included large teams of UK and European academics and technocrats, but also energy MNCs, such as Alstom, BP, Mitsubishi, Shell and Schlumberger were active participants. Overall, industry representatives outnumbered NGOs at these workshops (field notes, New Delhi, 21-23 January 2008). Furthermore, the chief sponsor for the DSDS in 2008 was the Norwegian Government, which hosted a high-level session, with various heads of state participating. This included speeches by the Prime Ministers of Norway (Jens Stoltenberg) and Denmark (Anders Rasmussen), both of whom notably endorsed CCS technology in their official address (field notes, New Delhi, DSDS 7th February 2008). Days prior to the DSDS event, Norway's Statoil signed a Memorandum of Understanding (MoU) with India's national Oil and Natural Gas Corporation (ONGC), which was an agreement to explore the potential of CCS projects in India, via the Clean Development Mechanism (CDM)[68]. The fate of this MoU is discussed in further detail in Chapter 7. The drivers behind these events in New Delhi can be interpreted through technological political realism, where countries with specific expertise supporting CCS technology were looking to expand into a new and potentially lucrative market. The Indian state was in essence the prospective customer. Furthermore, the same state actors, e.g. UK, Norway and EU, were the strongest proponents for including CCS within the CDM framework, and this issue is discussed in further detail below.

6.3 The role of CCS in the International Climate Negotiations

As discussed earlier, CCS technology has featured significantly within international legal discourse, particularly regarding climate and marine legislation. This section provides a broader view of CCS in an international context, where the focus is on responses of developing countries to the technology. Notably, India did not participate in the CCS-specific dialogue at Copenhagen in 2009. Nevertheless, the value of this discussion is to further demonstrate and highlight the political and commercial drivers behind CCS implementation in developing countries.

During the period of empirical research for this thesis there was no international mechanism to support the development or deployment of CCS in developing countries. The analysis here is largely concerned with the negotiations under the United Framework Convention on Climate Change (UNFCCC), specifically, the Clean

[68] See: http://www.statoil.com/en/NewsAndMedia/News/2008/Pages/CooperationIndia.aspx

Development Mechanism (CDM). Empirical research data was gathered in Copenhagen, Denmark, where the fifteenth Conference of the Parties (COP15) to the UNFCCC was being held. It should be noted that dialogue regarding CCS took place under four separate bodies[69] in Copenhagen; COP15 also served as the fifth Meeting of the Parties to the Kyoto Protocol (CMP5[70]), and the discussions that took place under this body is the focus of analysis here. The negotiations specifically regarding the inclusion of CCS within the CDM framework originally took place under the workstream of the Subsidiary Body for Scientific and Technological Advice (SBSTA), and these were also observed at COP15.

The deliberation about including CCS within the CDM framework had become a rather divisive issue in the lead up to COP15 (see de Coninck 2008); the discussions in SBSTA were often controversial, leading to heated debates, and the tone of these meetings were no different in Copenhagen (COP15). Interestingly, India was already notorious in 2008 for being one of the more vocal opponents to the inclusion of CCS under the CDM, particularly at COP13/CMP3 held in Bali, 2007 (Shackley & Verma 2008, p. 3558), and did not participate in any SBSTA or CMP5 meetings related to this matter at COP15. The reasons behind this are discussed in detail in the following chapter (see Section 7.2.2). However, despite India's absence at this particular discussion at COP15, a submission was put forward to SBSTA in December 2009 outlining the necessary steps required of the CDM project cycle, in order to provide an enabling framework for any potential CCS deployment in India via the CCS-CDM model (see Bumb & Rituraj 2009). It should be noted that this was not an official submission on behalf of the Indian Government, but rather from an NGO, the Indian Youth Climate Network (IYCN). The following section focuses on the CSS/CDM debate observed at COP15, highlighting the divide within the developing country parties, which can be

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[69] Discussions related to CCS took place under the following bodies at COP15: (1) Scientific Body for Scientific and Technological Advice (SBSTA); (2) Conference of the Parties serving as a Meeting of the Parties to the Kyoto Protocol (CMP); (3) Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP); (4) Ad Hoc Working Group on Long-term Cooperative Action (AWG-LCA).

[70] This is also referred to as a COP/MOP, shortened to CMP. The CMP was the Kyoto Protocol's supreme body, but only Parties that had ratified or acceded to the Protocol could participate in deliberations and make decisions, i.e. this excluded the USA. The Kyoto Protocol expired in 2012.

explained through technology politics and realism, but can also be viewed as a symptom of CCS operating as a sociotechnical system rather than a discrete technology.

6.3.1 CCS and the Clean Development Mechanism (CDM)

As one of the market-based mechanisms of the Kyoto Protocol (1st commitment period 2008-2012), the CDM allows Annex 1[71] Parties, essentially developed countries, to meet their commitments to reduce emissions based on actions taken in developing countries (Non Annex 1 Countries[72]). CDM projects undertaken in developing countries, according to Article 12 of the Kyoto Protocol, have to meet two main objectives. Firstly, CDM projects must contribute to the sustainable development needs of the host country and, secondly must generate Certified Emissions Reductions (CERs)[73], which are essentially emissions credits that can be bought by Annex 1 countries as an alternative to reducing their own greenhouse gas emissions. There has been expert analysis about the potential for receipt of revenues from CERs under the CDM as a possible mechanism for financing CCS demonstration in India (see Shackley & Verma 2008). However, a representative from the Ministry of External Affairs made India's resistance to CCS explicit prior to the negotiations at COP15:

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[71] Annex 1 to the UNFCCC is a list consisting of industrialised nation states, including the original twenty-four members of the Organisation of Economic Cooperation and Development (OECD) in 1990, as well as the European Union. This list also includes 'economies in transition' from Central and Eastern Europe, such as Croatia, Slovenia, the Czech Republic and Slovakia. Under Article 4.2 (a & b) of the Convention, these countries commit themselves to reduce their emissions to their 1990 levels of GHG emissions by 2000, as well as accept emission targets for the period 2008-2012 (see Birnie et al. 2009, p. 356).

[72] These are developing nations that have ratified or acceded to the UNFCCC.

[73] A CER represents one tonne of CO_2 equivalent greenhouse gas emissions reductions achieved through a CDM project.

"This is not a proven technology. Many technical parameters need to be still worked out. And, it's certainly not economically feasible because if we fit CCS equipment to a coal based plant, it would double the investment. We have deep reservations about this technology, particularly if the storage has to be in terrain that is geologically unstable." (Shyam Saran, special envoy of the Prime Minister on Climate Change, April 13th 2009)[74]

Therefore, India's absence from the CCS-CDM dialogue at COP15 came as no surprise. In a brief discussion with a representative from the Indian Ministry of External Affairs at the very start of the COP15 negotiations, it was mentioned that India did not think it likely for CCS to have much of a role within the first commitment period of the Kyoto Protocol, i.e. before 2012, and that CCS discussions would be more useful in workstreams focusing on post-Kyoto activities[75]. This would allow the USA to be involved in the discussions, as they are the most significant polluter and have the means to develop the technology (Interview B12 2009).

More generally, CCS has been thought of as a viable mitigation option for developing countries, where discussions surrounding its inclusion in the CDM date back to 2005 at CMP1, Montreal. This was initiated by Vietnam and Malaysia, who wanted the CDM Executive Board (EB) to consider two new CCS technology methodologies (see UNFCCC 2006). The EB decided that it was not sufficiently equipped to respond to this new methodology and subsequently created a new workstream under the Subsidiary Body for Scientific and Technological Advice (SBSTA) in 2006 (Dixon 2009). Since then, CCS had been on every agenda of subsequent SBSTA meetings, which entailed deliberation on this issue every six months. This involved submissions from Parties and NGOs (2007-2008), culminating in two synthesis reports. The workstream was due to conclude in December 2008, where a decision was expected at CMP4 in Poznan. However, even though a draft text was prepared and debated upon, a decision could not in the end be reached and the decision was referred

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[74] See Singh (2009).

[75] This refers to the Ad Hoc Working group on Long-term Corporative Action (AWG-LCA) and, the Ad-Hoc Working group on Further Commitments for Annex 1 Parties under the Kyoto Protocol – post 2102 (AWG-KP)

to the EB, who were requested to report back at CMP5 (Copenhagen) (Dixon et al. 2009). Notably, even though negotiations on potential CCS methodologies for the CDM were discussed under SBSTA to begin with, the ultimate decision to include CCS within the CDM could only have been made at the Ministerial-level by the CMP body[76].

In Copenhagen, the discussions on CCS inclusion within the CDM initially started in the SBSTA workstream, and the main arguments for or against are summarised in Table 6.1, derived from field notes (December 2009). Notably, the support for CCS came largely from oil-producing countries, and the opposition was led by Brazil, Grenada and Jamaica. The difference in opinion was mainly about how to proceed, where those in opposition thought the issue should be pushed back to the next SBSTA meeting in June 2010, whereas others wanted the issue to be addressed in Copenhagen and a final decision to be made by CMP5.

In order to understand the tensions within the CCS-CDM forum at the Copenhagen COP it is helpful to interpret this debate through a sociotechnical lens, combined with insights from technology politics and realism, given that the states are the main actors within an international legal forum and, the mixed sociotechnical identity of CCS (see discussion in Chapter 2). Firstly, in terms of technological political realism, states are acting in their self-interest and this is evident from the list of countries supporting CCS inclusion in the CDM (see Table 6.1). Supporters of CCS technology fall mainly within two categories; (1) those states that are major fossil fuel exporters, e.g. from the MENA[77] region, or (2) those developed states that not only export fossil fuel, but have established hydrocarbon industries that have already been exploring CCS R&D in their own regions, e.g. Norway, Australia, and the EU. Notably, of the EU member states, the UK has been the most active in the CCS-CDM debate and has contributed significantly through submissions on methodologies and assisting with developments to the European legislation regarding CO_2 storage and the European Carbon market (Dixon et al. 2009).

[76] This is because CMP serves as ultimate body of the Kyoto Protocol; the CDM is a market mechanism of the Kyoto Protocol.

[77] Middle East and North Africa

Table 6.1: Summary of the main arguments for and against the inclusion of CCS within the CDM framework, including lists of countries that either oppose or favour the motion (source: field notes, COP15, Copenhagen December 2009).

Countries AGAINST	Arguments AGAINST:	Countries FOR	Arguments FOR:
JAMAICA VENEZUELA BRAZIL RWANDA MICRONESIA PARAGUAY GRENADA/ AOSIS[78]	• Unproven technology; Currently no CCS [on coal power stations] yet in Annex 1 countries; Prove in Annex 1 first then transfer technology • CCS will flood CDM market with CERs, lowering CER prices, reducing incentives for renewables • Long-term liability – offset project that helps Annex 1 avoid domestic action in the short-term, e.g. host country would be left with responsibility in the long-term • Propagate inequitable distribution of CDM projects; already recognised that certain countries benefit more from CDM – e.g. China, India & Brazil are top countries with largest share of CDM projects • Does not meet sustainable development objectives; propagates further use of fossil fuels	NORWAY EU JAPAN AUSTRALIA ALGERIA KUWAIT QATAR SYRIA NIGERIA LIBYA KOREA UAE	• Climate change – all mitigation technologies should be applied especially if 2ºC rise/450 ppm by 2050, then role of CCS is approx 19% of mitigation action – take CCS out then 70% more expensive to achieve 450ppm • CDM is meant to be technology neutral • A new technology should involve joint-learning with developing countries • CCS may help with the equitable distribution of CDM projects – e.g. in Africa & South East Asia • Can be done now with non-coal CCS, projects are waiting, e.g. natural gas & other industries • Some developing countries argue that they are dependent on fossil fuels and have little other natural resources, therefore this is the only way to reduce emissions.

Moreover, the dominant role of industry should not be ignored, and naturally there was a lot of interest, evident by submissions from Business and Industry Non-

[78] Alliance of Small Island States (AOSIS) – is an ad hoc negotiating/lobby group comprised of low-lying coastal countries and small island states that are considered most vulnerable to the adverse effects of climate change. This group was formed because its members all have similar development challenges; their spokesman at COP15 was the negotiator from Grenada.

Governmental observer organisations (BINGOs), such as the Carbon Capture and Storage Association (CCSa), the Global CCS Institute (GCCSI), the International Petroleum Industry Environmental Conservation Association (IPIECA) and the World Coal Institute (WCI)[79]. It should be noted that although the aforementioned BINGOs are international organisations, they are all based within key developed nations, who were leading in CCS R&D at the time – UK and Australia. Even though there can be a liberalist interpretation of this situation regarding the involvement of BINGOs, i.e. NGOs are just as politically relevant as State actors, in this context, it can be argued that these BINGOs were still working together with State actors that had a strategic interest in the CCS-CDM debate.

In the context of Non Annex 1 countries for CCS inclusion, the strongest support came from oil-rich countries in the Middle East. For example, the UAE were very keen for its inclusion because they felt it was the only way they could participate within the CDM framework (field notes, Copenhagen, SBSTA 3rd Meeeting, 12 December 2009). In an interview with the negotiator, it was gleaned that the UAE were working towards building infrastructure for a CO_2 pipeline network that would enable the transport of CO_2 from various industries, such as cement, soda-ash and urea/fertiliser production. It was envisioned that this captured CO_2 would be transported offshore for EOR purposes (Interview B15 2009). Two factors explained their interest. First, although this project was being subsidised by the state, the UAE Government wanted that portion of funding or subsidy to be paid by the CDM instead. Second, notwithstanding the increased oil production from offshore EOR, the UAE were keen to lead on the technology for export purposes, and needed the CDM money to achieve this (*Ibid.*). When questioned about the cost of developing the capture technology, as it is both energy intensive and costly (see Chapter 4), the negotiator said that there was enough profit from gas and oil exports, so they did not feel impeded by such costs (*Ibid.*). Accordingly, when analysed through technological political realism, not only is there an element of national-interest, but also there is interstate competition and technology; in this context CCS is seen as an exogenous instrument by which to gain a competitive edge.

[79] A full list of submissions is available here: http://cdm.unfccc.int/about/ccs/index.html

When the CDM debate is considered through the second theme of the mixed and multiple identity of CCS, then some of the issues highlighted as counter-arguments in Table 6.1 stem from difficulties in defining the technology, which throws its eligibility for the CDM into question. This is linked with its questionable role as a mitigation tool and the argument that CCS does not really contribute to sustainable development, which is a core ethos of the CDM. For example, the first two submissions that initially sparked this debate were related to CO_2 EOR offshore in Vietnam and, CO_2 separation from LNG processing in Malaysia (see UNFCCC 2006). In both of these cases, it can be argued that the objective was not entirely based on mitigation, i.e. the aim was to extract more oil in Vietnam using CO_2 EOR, and the reservoir in Malaysia was CO_2 – acid rich, and CO_2 needed to be separated in order to sell the gas. In addition to the questionable mitigation objectives, there is also the issue of whether these processes would qualify as 'new' technology or rather would entail the use of existing practices and techniques, e.g. 'gas sweetening' in Malaysia. Moreover, one could question whether these proposals are actually an opportunistic way to get money for something that would have to be done regardless, in order to extract the resource. The submissions by Vietnam and Malaysia can be best explained through technological political realism discussed earlier in this section.

The following field note extracts demonstrate that countries resisting its inclusion were not convinced that CCS was a legitimate mitigation tool, or a proven and coherent technological system:

Serendipitously sat next to the negotiator from Grenada at lunch today. This was just after a very intense Contact group meeting, having witnessed, literally, a shouting match between Saudi Arabia and AOSIS (mainly Grenada & Jamaica). The negotiator raised some concerns regarding CCS in the CDM and would like me to investigate. AOSIS have limited support staff; as an observer from University of Edinburgh, I was considered a neutral party and therefore suitable to provide some assistance in terms of research. His concerns included:

- Not sure if CCS meets the eligibility criteria as the right kind of technology for the CDM – "isn't it similar to nuclear?"

- There are concerns regarding permanence – "how do we know that it will all stay below ground? If it will then why isn't everybody doing it already?"

- Benefits seem to be in the short-term, and primarily for private industry. In the long-run, the host Government takes on the liability, so "is it possible to get CERs back if there is leakage then?"

- CCS seems like a hypothetical technology, not convinced that carbon reduction units would be real, measurable or verifiable.

(Combined field notes and Interview B14, COP15, Copenhagen, 10th December 2009).

From the field notes above, it is evident that the negotiator considered CCS technology difficult to define, which is why its eligibility under the CDM was being questioned. There is also an association with nuclear technology due to the long-term storage of waste underground; hence leakage is a major concern. The negotiator felt that CCS was 'overcomplicating things', where the focus should be on technologies that are proven to work in developed countries first. Moreover, he wasn't convinced that CCS would benefit the host country in terms of sustainable development or the mitigation process as a whole, because it was not clear that the emissions reductions could be verified or measured (Interview B14 2009). The observations and analysis of de Coninck (2008) and Dixon (2009) corroborate these findings.

Even though India did not feature in the negotiations analysed here, the reservations voiced by other developing countries reflect the scepticism expressed by majority of Indian stakeholders surveyed. In terms of international fiancial mechanisms for facilitating technology transfer, the majority of stakeholders surveyed (13/18) felt that the exisiting infrastructure of the CDM and carbon markets were insufficient to support and promote CCS technologies (Survey 2009, Appendix B). Moreover, a survey respondent opined “that CDM and carbon markets of the future will not give enough support to CCS, for which investment is much higher than other low carbon technologies” (Respondent 14, Survey 2009, Appendix B & C). It was also considered that “policy changes that allow CCS to be part of the CDM will be insufficient due to the energy penalty [associated with] the technology” (Respondent 13, Survey 2009, Appendix B & C). In fact, the overall process of technology transfer was met with some scepticism; it was considered to “just mean being directed to a private company, which in turn charges large amounts of fees to share the knowledge of the technology” (Respondent 16, Survey 2009, Appendix B & C).

A decision regarding CCS and the CDM could not be reached by the Ministers at CMP5, and the issue was pushed back to the following COP/MOP at Cancun, Mexico in 2010. Notably, at CMP6 the following year, a decision was reached to include CCS within the CDM framework, provided specific issues related to procedures and methodologies were addressed, e.g. strengthening monitoring plans of any potential CO_2 leakage during the crediting period and after (i.e. post-injection) (see Dixon et al. 2013, p. 7592). Decisions made within the UNFCCC process are inherently political; agreements are reached by means of *consensus ad idem*, wherby all contracting parties must agree to identical terms in order to reach a formal agreement (see Martin & Law 2006). Therefore it is possible for countries to hold debates ‘at ransom’, and in the case of CCS, this was quite apparent in Copenhagen. A form of bartering was observed outside the formal negotiations; for example, towards the end of CMP5, Brazilian negotiators were willing to “trade off” CCS if countries would support the eligibility of ‘Forests in Exhaustion’[80] under the CDM (Field Notes & Interview B16 December 2009, Copenhagen). In line with general observations made at this international forum, it became clear that there was a distinct conflict of interest in terms of climate change goals and development ambitions for all nations paticipating. It can be argued that political realism prevails in an international arena which was supposedly formed on the basis of political liberalist values, i.e. where there is a growing interdependence

[80] This was another contentious issue at the CDM debate in Copenhagen. Brazil’s proposal was to allow contracting parties to the KP to be able to redeem CERs for re-establishing a commercial plantation on degraded land, also referred to as ‘Forests in Exhaustion.’ See: http://www.ecosystemsclimate.org/LinkClick.aspx?fileticket=JBoMS8b4wSE%3d&tabid=1602

between multiple actors, e.g. States, NGOs and MNCs, for cooperation at the global level (e.g. de Coninck 2009; de Coninck & Bäckstrand 2011). However, the CCS-CDM debate highlights that States act largely according to national self-interests, which tend to dominate or dictate the debate (de Coninck & Bäckstrand 2011).

6.4 Conclusions

This chapter explores the significant international dimensions of CCS, particularly the international effort to entice India to take an interest in the technology. This strategy involved engaging India in CCS dialogue via two channels: first, through bilateral workshops and conferences, funded by the UK government or the European Commission, held during the beginning of the study period; second, by means of the UNFCCC forum, where CCS was proposed as a mitigation option under the CDM framework. Notably, India aired deliberate caution regarding CCS at these international initiatives; from the outset India's position has been against any demonstration or deployment on Indian soil, in addition to opposing the inclusion of CCS under the CDM. Interestingly, despite being a key target for CCS promotion by Western Governments and MNCs, India's role on the international stage was for most of the time minor during this period of study, especially during the climate negotiations in Copenhagen in 2009.

In order to understand India's official international position on CCS technology, it is important to consider its domestic policy approach to climate change. India consistently emphasises the importance of historical responsibility, and therefore in 2007-10 was not prepared to take on mitigation commitments if not based on the principle of CBDR. In the Indian Government's view, development objectives could not be separated from actions on climate change; rather, there was a philosophy of 'co-benefits'. Therefore, the contribution of CCS to sustainable development was questioned, not only by India, but also by several other developing countries, as observed at COP15 in Copenhagen.

At various international CCS events taking place in New Delhi, the Indian Government declared that any CCS deployment and demonstration in India would be 'premature'. The primary reasons given were due to its cost and inefficiency, but also because it was yet to be demonstrated as safe and commercially viable in other countries. Furthermore, India felt pressured by the international community to consider CCS, despite being vocal in international meetings regarding its reservations about the technology. Consequently, most events attended, both in New Delhi and Copenhagen were contentious, and the political and commercial objectives behind hosting such events were apparent, given that they were all sponsored by developed states and MNCs with a strategic interest in developing CCS.

Connected to these commercial drivers behind CCS technology transfer is the significant challenge of addressing concerns regarding the protection of IP belonging to MNCs. Issues related to IPR can be regarded as an impediment to technology transfer in general, and have been an established point of contention with the international negotiations on climate change. The protection of IP relating to CCS in particular becomes more challenging due to its complexity, e.g. certain sectors are more prone to employing trade secrets, such as the oil & gas industry, which are more difficult to transfer between countries. This adds to its mixed sociotechnical identity – CCS is combination of both old and new technologies and institutions, and therefore hard to define.

Throughout the study period (2007-10) India maintained the position that CCS technologies had to be deployed and demonstrated in developed countries first before they would be considered in India. Therefore, in the lead up to COP15 in Copenhagen, India was known for being vehemently against the use of the CDM framework to support CCS technology transfer. Notably, India did not participate in the CCS-CDM debate observed in Copenhagen 2009. Despite India's absence, it was interesting to observe the arguments for and against CCS inclusion in the CDM, and the divisions within the overall developing country negotiating bloc. The CCS-CDM debate was dominated by fossil-fuel states, which naturally had a commercial imperative to invest in CCS. The next chapter looks at CCS specifically regarding the domestic context and the sociotechnical issues surrounding the different parts of the technology chain. A more in-depth exploration, using the Cambay Basin case study, further explains the complex interplay of politics and technology which led to India not implementing CCS.

Chapter 7: Feasibility of CCS in India – Domestic Context and Challenges

7.1 Introduction

Previous studies show that the Indian government expresses minimal interest in CCS demonstration or policy (e.g. Narain 2007; Shackley and Verma 2008; Rajamani 2011), and this research also found the same. As discussed in Chapter Six, the Indian Government considers CCS to be a technology of the future, which needs further development in industrialised countries first in order to bring down the cost through R&D and deployment. Furthermore, during the period of empirical research for this thesis (2007 – 2010), the Indian Government held the position that CCS was not a viable option for climate change mitigation in India, and therefore would not agree to any further assessment of CO_2 storage potential, nor were they considering setting up any demonstration or early deployment projects. Therefore, from the onset of this research project, India did not looked favourably upon CCS, and as outlined in Chapter One, a key objective of the thesis is to explore and better understand why this was the case.

In this chapter a range of technical options for the domestic implementation of CCS in India – introduced in Chapter Four – are explored in more detail, including: integration of CCS with a range of new types of power plant built or planned in India; the composition of coal mined in India; and geological storage. These technical issues are shown to be *socio*technical, infused with domestic and international politics (e.g. security issues) and economics. This chapter explores in detail the technological and political issues to do with of CCS implementation in India, which are bound up with particular limitations at the domestic level. For example, India's key domestic challenges are to do with geology and outdated energy infrastructure such as inefficient power plants, in addition to, social concerns related to corruption, theft and insurgency in coal-rich areas. These issues could not be discerned from the international discourse analysed in the previous chapter and therefore, this chapter explores in detail how these domestic issues have also influenced the Indian Government's international stance on CCS (as presented in Chapter Six). Moreover, a case study on the Cambay Basin, which was selected as the most promising sociotechnical site for CCS in India, is used to further explore how these complex challenges to CCS technology transfer in India have manifested. This case study includes an exploration of both technical aspects and political dimensions, in keeping with the theoretical frames introduced in Chapter Two, including the mixed identity of CCS, innovation and technology transfer, as well as the importance of international relations on these aspects.

A series of elite interviews[81] were conducted, with representatives from twenty-five different organisations, predominantly Government and industrial sectors, as well as an expert stakeholder survey (see Appendix A, B and C), in order to assess in detail the sociotechnical context for the implementation of CCS in India (see Chapter Three for more details, especially Table 3.1 and 3.2). This data is drawn upon throughout Chapters Six and Seven, including the Cambay Basin case study.

It is noted in Chapter 5 (see section 5.3) regarding India's energy system that there are technical issues that make CCS challenging specifically for India, notably, the geological constraints. These technical geological issues are also a vital issue in explaining India's attitude towards CCS and its failure to implement CCS in the period 2007-10. Specifically, India's geology impacts not only the storage aspect of the CCS chain, but also the poor quality of Indian coals requires unique capture technology to deal with its high-ash content. Section 7.2 explores the technical and geological feasibility of current CCS technologies in the Indian context. However, the political dynamics associated with India's main fuel choice, coal, also influences India's decision on CCS, and these aspects are discussed in Section 7.2.1 before looking at the whole CCS chain as potentially applied to India (i.e. capture, transport and storage). Finally, the case study of the Cambay Basin is presented in Section 7.3, going further in detail of both the technical potential in the region, as well as the social and political context that could undermine a potential CCS project. Some geopolitical dimensions of the case study, particularly in the context of shipping, are also explored later in this chapter, because, in geographical terms, the Cambay Basin is part of the Indian sub-continent, and essentially the original source of CO_2 is physically located there. Therefore, these

[81] All interviews were confidential; the names of interviewees are withheld by mutual agreement. However, their position is provided as an indication of their 'elite' status in Chapter Three, Table 3.2, p.72-75.

geopolitical dimensions exist only *after* domestic challenges are met and the CO_2 physically leaves India.

7.2 Putting CCS Technology into an Indian Context

Chapters Two and Four demonstrate the complexities associated with CCS technology, both in terms of its innovation and development, as well as its flexible technical configuration, i.e. the integration of three distinct stages (capture, transport and storage). CCS thus has a mixed identity – it is actually a bundle of different types of technology, a sociotechnical system – and this is also reflected in how CCS has been perceived in India, as discussed in Chapter Six. This section explores CCS technology suitability to Indian local conditions, specifically in terms of the technical issues raised in Chapter Four.

7.2.1 Externalities Regarding Coal

Chapter Five explored the significant role that coal plays in India's energy system, and, if CCS is truly going to make a considerable impact by mitigating CO_2 emissions, then coal-based power will need to be where it is applied. Therefore, this section starts by exploring the very beginning of a potential CCS chain, i.e. the fuel source. This is because CCS implementation, especially on power plants reliant on indigenous coal, would perpetuate the mining of coal in India. The negative social and environmental impacts of mining for mineral resources and coal are well documented (see Josephson 2006; Sudarshan & Noronha 2009; Marston 2011). Particularly, in the case of India, the mining is largely opencast because it is cheap, and manual labour is readily available (Sudarshan & Noronha 2009). Typically, international financial institutions, such as the World Bank, have contributed to "large-scale technological development projects", especially energy projects, but failed "to understand or overlook[ed] their significant social and environmental impact" (Josephson 2006, p. 152; see also Chellaney 2011; Marston 2011). For example, Singrauli (Madhya Pradesh) provides 10% of India's coal-based power and was initially set up as the 'coal hub' by the World Bank; but rather than providing electricity locally, it supports large urban centres, leaving the locals in a state of perpetual poverty and depravation (see Marston 2011). In the context of this study, the legacies of major coal projects, as well as, other extractive industries, have created an unstable domestic situation in India, and they continue to create further discontent. A key official within the Ministry of Environment and Forests commented that this malaise, largely due to poor governance, has already created much concern for the Indian Government and India will "need to get its house in order first" before considering any other new technology (Interview A2 2008). He added, too many people have suffered, lost livelihoods and lives; "such land grabs were all made in the name of development and energy security, but the country cannot continue on this path" (*Ibid.*).

For two reasons, Indian coal is considered to be a rather dangerous commodity by Indian policymakers, with serious implications for national security. First, there is an issue regarding the accuracy of coal resource estimates (see also Section 5.3), which is linked to political corruption and illegal mining. In an interview with a senior coal R&D specialist for Coal India Limited[82] (CIL), it was highlighted that mines were already being operated unsustainably to cope with the increased demand; he was of the opinion that with current rates of consumption, the extractable coal is likely to run out by 2030 (Interview B2 2008). He added further, significant amounts of produced coal are unaccounted for and there is widespread illegal mining, due to corruption, which goes up through the hierarchy to very senior levels, or by organised gangs (*Ibid.*). Commenting more on the former than the latter, the interviewee from CIL mentioned that due to the lack of transparency and corruption within the sector, there were major discrepancies when it came to the allocation of coal blocks to mining companies, to both public and private companies. Therefore, the interviewee concluded that official figures are very likely to be inflated and he was of the opinion that neither the future projections of coal-use made by Government reports, nor Indian coal availability, could be relied upon (*Ibid.*). This has implications for any potential CCS project that is to be based on Indian coal, especially as CO_2 capture involves *more* coal use (see Chapter 4). Moreover, an unreliable fuel source has consequences for the overall operation of the power plant.

During 2008, the Central Bureau of Investigation (CBI) had already been investigating various scams connected with the coal sector and illegal mining in

[82] CIL accounts for nearly 85% of coal production in India; it is a state-run enterprise.

resource-rich states such as West Bengal and Chhattisgarh (see Mittal 2008; Pandey 2009). On 22nd March 2012 the Times of India, having obtained a draft copy of a report by the Comptroller and Auditor General (CAG) of India, reported that the Indian Government had incurred losses of "Rs10.67 lakh crore [or 10.67 Trillion Indian Rupees[83]], to commercial entities by giving them 155 coal acreages without auction between 2004 and 2009" (Dutta 2012). The CBI connected this scam to the highest political office, investigating the Indian Prime Minister at the time of this study, Manmohan Singh, who was also in charge of the Ministry of Coal from 2004 to 2009 and since then, the Indian media have dubbed the whole affair as 'coalgate' (see Kumar 2013; PTI 2014). The controversy over the allocation of coal blocks without competitive bidding remains a hot topic within public discourse and the Indian media (*Ibid.*). Given the large amounts of capital investment that a potential CCS project would require upfront, working with Indian coal would likely be considered a high-risk option for multinational corporations (MNCs). This is because the Government's credibility had been shaken in 2011 due to political corruption scandals, and extensively profiled in the media, regarding its senior officials and the so-called 'mining barons' (Thakurta 2011). In terms of prospective CCS technology transfer, MNCs would be required to cooperate with nationalised sectors, which are most likely to own and operate parts of the CCS chain. For example, as highlighted in Chapters Four and Six, MNCs are currently leading in CCS R&D and will have a crucial role to play in any technology transfer. There are very strong commercial drivers for CCS implementation alongside the role of state actors. However, this thesis does not explore the role of MNCs because the during the study period state actors took precedent in regards to implementation.

The second reason why Indian coal is considered a risky commodity is connected to the illegal mining discussed above, which has resulted in a thriving black-market economy of coal. There is also evidence that this directly supports India's Maoist insurgency. Ramana (2011, p. 29) explains that the origins of this insurgency started in the late 1960s, and "all those who have subscribed to the idea of an armed overthrow of the state have been generically referred to as Naxalites, the term having its origins in

[83] When this story broke, the BBC converted the South Asian units of currency, and estimated the loss to be equivalent to USD210 Billion at the exchange rates of that time (see BBC 2012).

Naxalbari village," located in the coal and mineral-rich state of West Bengal. Furthermore, "the largest and most lethal of all Naxalite groups in operation in India" is the Communist Party of India (Maoist), or CPI (Maoist)[84], and is "avowedly committed to waging an armed revolution and consider[s] parliamentary politics a sham" (Ramana 2011, p. 29). The CPI (Maoist) group has become a stronger threat over the years, and now poses a huge security risk in resource-rich states, so much so that the Indian Government equates them with terrorists who are "out to destabilize the country and impede 'development', which is understood to mean industrialization" (Sundar 2011, p. 47).

However, it should be noted that the vast majority of India's coal is located in densely forested areas and tribal regions, and the root cause of the upsurge in Maoist attacks is connected to the poor governance and unsustainable mining practices conducted in these areas. Both the Ministry of Environment and Forests (Interview A2 2008), and the Centre for Rural Development (Interview B3 2008) criticized Indian Government policymakers for treating tribal areas as "simply mineral-rich areas to be exploited", with total disregard for the local population, who have been displaced as a result of large development projects. Furthermore, interviewees felt that this increase in discontent amongst the locals is because both public and private enterprises that operate in the area have failed to fulfil any environmental or social obligations to the people, whose land they have acquisitioned (Interview A2 2008; Interview B3 2008). This is further corroborated by the work of Marston (2011), which highlights the plight of local people in Singrauli district (site of major World Bank power projects), where, despite being based in the 'coal capital' of India, they lack jobs, electricity, clean drinking water, and live in abject poverty. Though, the Minister insisted that even though there is "unbelievable pressure" from the coal and power sectors for land acquisition and land clearances, He was strong in its support for protecting these areas (Interview A2 2008). The data discussed in this chapter highlights a wider, ongoing

[84] The Maoist insurgency gets its name because during the 1970s "the movement received the complete backing of China; the Communist Party of China extended guidance, financial support and training to the leadership [of the CPI (Maoist)]" (Ramana 2011, p. 31).

conflict-of-interest within India's domestic political scene (see footnote below)[85], and the influence of this matter on CCS is further illustrated below in Section 7.3. Nevertheless, mining still implies land clearances, and decades of industrial development in these regions have created a great deal of instability. The high-security risk of operating a power plant with CO_2 capture and transport in such areas will need to be considered by all, taking into account not only those parties invested in such a project but also the local population that would be impacted.

Exploring further the security implications of operating coal and power plant projects (a situation which CCS would perpetuate), interviews were conducted with two, recently retired, senior Indian police officers who had worked extensively in India's coal–bearing states of Bihar, Jharkhand and Uttar Pradesh (Interview B7 2008; Interview B8 2008). Both security professionals were of the opinion that the flourishing black-market coal economy was largely responsible for funding the Maoist insurgency, and this was connected to an entrenched coal mafia culture, where the coal industry is best described as "a lawless and dangerous business" (*Ibid*.). The retired Director General of Indian Police Service (IPS) branch Jharkhand, a densely forested and mineral-rich state, described the coal sector as essentially being governed by powerful overlords, often referred to in the media as 'coal barons', who employ large armed gangs to protect their assets. Currently, this is the case for both legal and illegal mining operations, as even private industries that have obtained 'legal' permits and contracts for production require professionally trained and armed guards to protect their assets from the insurgency (Interview B7 2008). Both officers observed that, over

[85] Through various interviews it became apparent that not all Government Ministries have similar positions when it comes to India's energy and development sectors. The Ministry of Power (MoP) is by far the most powerful, wielding influence over the Ministries of Coal, Oil & Gas, and Science & Technology amongst others. The Minister of Environment & Forests (MEF) at the time of this study was very outspoken against several Government and private sector development initiatives. Despite the open tensions between the MEF and the MoP, when it came to climate change all of the Ministries put up a united front. Notably, the Minister of the MEF had significant presence at the UNFCCC COP15 negotiations, and was arguably one of the chief architects of the emerging economy negotiating bloc at the ministerial-level (including Brazil, China, South Africa and India). At COP15 the Indian NAPCC was promoted by the MEF as something other developing countries could potentially emulate (Field notes, December 2009). In 2011, the Minister of the MEF was appointed as the Minister of Rural Development in a cabinet re-shuffle.

time, the weaponry of insurgents has become more and more sophisticated, indicating that there has been an increase in monetary support for the insurgency movement, most likely from selling coal and other resources on the black market (Interview B7 2008; Interview B8 2008). Moreover, mines in particular are considered to be targets because they are also a source of explosives, which are generally used for blast-mining purposes (*Ibid.*). The retired officers described the situation on the ground as a vicious cycle, that has gone out of control; not only do the mining operations create instability, e.g. by land grabbing, they also become a key resource for ammunition to be used by the insurgency, and so the mining companies respond by hiring more armed guards (*Ibid.*). This situation is further exemplified by the work of Miklian & Carney (2010), reporting an incident that took place at an iron mine in 2006:

> *"The richest iron mine in India was guarded by 16 men, armed with Army-issued, self-loading rifles and dressed in camouflage fatigues. Only eight survived the night of Feb. 9, 2006, when a crack team of Maoist insurgents cut the power to the Bailadila mining complex, [Chhattisgarh] and slipped out of the jungle cover in the moonlight. The guerrillas opened fire on the guards with automatic weapons, overrunning them before they had time to take up defensive positions. They didn't have a chance: The remote outpost was an hour's drive from the nearest major city, and the firefight to defend it only lasted a few minutes.*
>
> *The guards were protecting not only $80 billion-plus worth of mineral deposits, but also the mine's explosives magazine, which held the ammonium nitrate the miners used to pulverize mountainsides and loosen the iron ore. When the fighting was over and the surviving guards rounded up and gagged, about 2,000 villagers who had been hiding behind the commando vanguard clambered over the fence into the compound and began emptying the magazine. Altogether they carried out 20 tons of explosives on their backs -- enough firepower to fuel a covert insurgency for a decade." (Miklian & Carney 2010)*

Notably, other than the mines themselves, research by Ramana (2011, p. 35) on India's Maoist insurgency shows that a growing number of attacks in the central-eastern states of India specifically target infrastructure projects, with a focus on key sectors such as oil and natural gas, coal, transport and power, aiming to bring production to a halt. The targets include power stations, mines, transmission poles, steel plants, cement plants, telecommunication towers and pipelines (see Table 7.1). From 2006-2010, attacks more than doubled, where the total was 71 in 2006, which increased to 171 in 2010 (Ramana 2011, p. 38-39). This rise in attacks is not just the story of a single state, rather an entire region. Both officers pointed out that it was no coincidence that the Maoist movement was gaining support in resource-rich states (Interview B7 2008; Interview B8 2008), and Miklian & Carney (2010) note "if you were to lay a map of today's Maoist insurgency over a map of the mining activity powering India's boom, the two would line up almost perfectly." This is also demonstrated by the data presented in Table 7.1. Furthermore, several interviewees (Interview A2 2008; Interview B2 2008; Interview B7 2008; Interview B8 2008) were of the opinion that such issues of national security, if not addressed properly, would eventually lead to civil war, as the CPI (Maoist) group are gaining numbers daily, across a region covering approximately a third of the country. It should be noted that given the sensitive nature of this information, the apprehension regarding India's coal sector first became apparent through interviews with policymakers during the first research field trip (i.e. Interviews A2 & B2). These issues were investigated further with in-depth interviews with security professionals after the first field trip (i.e. Interviews B7 & B8). Notably, these kinds of concerns regarding the coal sector were not obtained from the survey data, even though anonymity was assured. Nevertheless, all survey respondents considered coal to be 'king', and, crucially for this thesis, that CCS implied a continuation of India's coal sector (Appendix A & B).

Table 7.1: Maoist attacks on infrastructure projects by Maoists 2006 – 2010 (adapted from Ramana 2011, p. 38-39; continued on next page).

Year of Attacks	***2006***		***2007***		***2008***		***2009[86]***		***2010***	
Target	Location (State)[87]	No.	Location (State)	No.	Location (State)	No.	Location (State)	No.	Location (State)	No.
Railways	Andhra Pradesh Bihar Chhattisgarh **Jharkhand** Maharashtra Orissa	33	Andhra Pradesh Bihar **Chhattisgarh** Jharkhand Orissa West Bengal	47	Andhra Pradesh **Bihar** Chhattisgarh Jharkhand West Bengal	27	Bihar Chhattisgarh Jharkhand **Orissa** West Bengal	15	Bihar Chhattisgarh **Jharkhand** Orissa West Bengal	35
Mining	Bihar Orissa	2	Andhra Pradesh **Chhattisgarh** Jharkhand	6	Chhattisgarh **Jharkhand**	6	--	0	Maharashtra	1
Power Plants	Andhra Pradesh Chhattisgarh	4	Andhra Pradesh	3	Maharashtra	1	Maharashtra	2	Maharashtra	1

[86] The data available for 2009 is only from Jan- June; this is because 2009 was also the year for general elections.

[87] The highest proportion of insurgency attacks occurred in the States depicted in **bold.**

Year of Attacks	***2006***		***2007***		***2008***		***2009*** [88]		***2010***	
Target	Location (State) [89]	No.	Location (State)	No.	Location (State)	No.	Location (State)	No.	Location (State)	No.
Transmission Lines/Poles	Chhattisgarh	5	Chhattisgarh	10	Chhattisgarh Orissa	24	Chhattisgarh	3	--	0
Other Relevant Infrastructure (e.g. Steel & Cement Plants; Pipelines; Rural Road Construction; Telecommunication Towers)	Andhra Pradesh Bihar **Chhattisgarh** Jharkhand Maharashtra Orissa	27	Bihar **Chhattisgarh** Maharashtra Orissa	14	Andhra Pradesh Bihar **Chhattisgarh** Jharkhand Maharashtra	51	Bihar **Chhattisgarh** Jharkhand Maharashtra **Orissa**	36	Andhra Pradesh Bihar Chhattisgarh Jharkhand Madhya Pradesh **Orissa** West Bengal	38
Other (e.g. school buildings; rural offices etc.)	--		--		--		--		--	96
Total Number of Attacks	***71***		***80***		***109***		***56***		***171***	

[88] The data available for 2009 is only from Jan- June; this is because 2009 was also the year for general elections.

[89] The highest proportion of insurgency attacks occurred in the States depicted in **bold.**

Furthermore, a retired Police Inspector, who had served in several mining districts in the states of Bihar and UP, described how and why violence in the region has escalated:

> The general practice by extractive industries has been to clear forested land, and the local tribal population is removed usually by force. These enterprises don't benefit the locals, who tend to be tribal people that relied on the forest for sustenance. The benefit goes to outsiders, who are brought in to operate the plant or mine, and the owners make windfall profits, lining their pockets with enough resources to allow them to become MPs for the region. This has resulted in the local villagers either joining or supporting the insurgency movement.
>
> Those who don't pick up arms to join the Maoists, they join mafia gangs to pilfer coal, which is then sold on the black market. This is the only way that they can earn a living, feed their families; the only work available in these regions is as unskilled labourers. In addition, gangs involved in illegal mining also have access to this labour force. The victims are the local tribes people. However, not all rebel leaders are out fighting for 'the people', rather many tend to be opportunists, in it for the money by selling commodities, such as coal, on the black market (interview notes, Interview B8, 6 April 2008).

Overall, interviewees (Interview B2 2008; Interview B7 2008; Interview B8 2008) were of the notion that sometimes these particular security-related aspects made MNCs or other private investors reluctant to participate in the coal sector, despite recent government initiatives to encourage private sector involvement. For example, as discussed in Chapter Five, India's coal sector was highly nationalized in the 1970s (see Section 5.2.3). However, in 2009 the Coal Ministry started negotiations to amend the Coal Mines Nationalization Act of 1973 in order to sell up to 10% of CIL, and successfully managed to raise $3.5 billion on the Bombay Stock Exchange (Ebinger 2011). However, the research data indicated that the security issue regarding Maoists was a cause for concern, particularly for setting up projects connected with pit-head plants, i.e. power plants in close proximity to the mine (Field notes, GHGT9, discussion with a representative from NTPC, Washington DC, November 2008). The interviewee (Interview B9 2008) worked for India's National Thermal Power Corporation (NTPC), which was at the time collaborating with a foreign MNC that specialises in providing turbine parts to power projects. In regards to the Ultra Mega Power Plant (UMPP) projects, he was concerned about the pit-head projects based in these coal-bearing states, and was of the opinion that some might not go ahead. He was of the opinion that it would "be an age" before they came online (*Ibid.*).

The relevance of these security issues for the thesis is to highlight the complex and highly politicised sociotechnical context in which CCS was being considered in India during the study period. The Maoist insurgency is an important issue for CCS because the targets are key parts of any potential CCS chain, and this has implications if projects were going to be considered in this area. Furthermore, it highlights an issue regarding the government's ambition versus public acceptability. Several UMPPs were in the planning stages during the study period, and are discussed in more detail in the following sub-section.

Moreover, the issues highlighted here have implications for India in terms of energy security and, such circumstances are more likely to push India towards coal imports. The surge in demand for electricity has been so considerable that India has already started diversifying its sources of supply and is getting coal imports from as far afield as Columbia (India has typically relied on imports from Australia, Indonesia and South Africa) (Chaudhary & Sethuraman 2010). Therefore, an alternative route to CCS implementation, proposed by UK technical studies at the time of my fieldwork (e.g. IEAGHG 2008; MottMac 2008a; MottMac 2008b), was to design a capture system based on imported coal, rather than India's indigenous coal.

7.2.2 Capture in the Indian context

As highlighted by the review of India's energy system in Chapter Five, the current fossil-fired power fleet in India is dominated by coal plants with subcritical steam conditions, which are not as efficient and therefore unlikely to be suitable for retrofit capture systems (IEA 2012). In addition, Indian coals are of poor quality, with high moisture and ash content, which affects combustion rates and efficiency (see Section 5.3; IEA 2002a). The poor quality coal in India is a key technical (geological) reason why CCS was not considered a feasible technology to implement in the country, and was an issue emphasized repeatedly at workshops and conferences attended in 2008 (see Chapter 6 & field notes below). Nevertheless, despite this issue being highlighted, it was largely overlooked or perhaps ignored by the international diplomats and experts trying to encourage India to commit to CCS (see Chapter 6). This situation is curious, and deserves further exploration to better understand the persistence of international CCS advocates in the face of India's stated lack of interest and poor technical suitability (see Sections 4.3.1 and 6.2.2).

India's priority, in the context of developing its power generation, has always been efficiency; mandated by its Energy Conservation Act (2001), key energy-intensive industrial sectors, such as thermal power generation, steel, cement and fertilizer production are required to undertake energy audits periodically (NAPCC 2008, p. 24). India's National Action Plan on Climate Change (NAPCC) also has a 'National Mission for Enhanced Efficiency' and it further outlines the types of initiatives considered by the Government in order to reduce GHG emissions from power generation. These initiatives include supercritical technologies, Integrated Gasification Combined Cycle (IGCC) Technology and natural gas-based power plants (NAPCC 2008, p. 38-39). Though, the Indian government intends to invest more in modern technologies, it is the entry of captive power plants from the private and industrial sectors which has brought in more efficient means of electricity generation into the country (see discussion in Section 5.3.2 & Joseph 2010). If CCS had been considered a viable option by India, then the captive power sector might have been an appropriate sector to use for an initial CCS retrofit demonstration, as many run on imported coal or gas, and therefore have a higher efficiency. However, as discussed in Chapters Four and Six, justification for CCS technology is to reduce CO_2 emissions, *not* increase efficiency. In fact, some of the capture technologies presented in Chapter Four are more energy intensive and would therefore require burning *more* coal per unit of electricity generated. Moreover, as discussed in Chapter Six, India does not feel obliged to cut its carbon emissions nor its use of coal, given that the developed world is just as dependent on the fossil fuel, and at the time of this study, had yet to demonstrate a full CCS chain.

Given that India's priority is to improve efficiency *first*, before it can consider any new technology, there are site-specific conditions that need to be considered for the base power plant choice (e.g. pulverised coal combustion; gasification of coal; gas-fired etc.). This will also influence any potential CO_2 capture approach used if in the future

India decides to integrate CCS technology into its energy system. Some of the India-specific conditions related to its power sector were discussed during the workshops attended in 2008 on fieldwork (see Table 3.1) and the main challenges and proposed measures are listed below:

> The following list is derived from combined field notes of the two phases of the EU-India Working Group Meetings, i.e. these issues were raised at both meetings (presentations by Central Electricity Authority (CEA), "Clean Coal Technology in India," 21st January 2008, New Delhi; National Thermal Power Corporation (NTPC), "Power Generation in India," 27th November 2008, New Delhi):
>
> 1) Current power fleet is very old; efficiency is roughly 35%.
>
> 2) Need efficiency of power plant to be higher than 40% for potential capture retrofit; therefore not economical to use with older stations.
>
> 3) Low efficiency due to high ash content of Indian coal (approx. 40-45%); this means coal is slow burning, and highly abrasive with high ash fusion temperature, which affects the design of boiler.
>
> 4) Also, transmission and distribution losses are high, approx. 15%-20% depending on the state; generally losses are technical.
>
> 5) There are plans to retire the old units with low efficiency, and increase share of renewables such as wind, solar and biomass; plus plans to increase share of nuclear power.
>
> 6) Very interested in supercritical technology in order to reduce coal consumption and GHG emissions, as well as increase efficiency.
>
> 7) Upgrades planned to old fleet involve switching to supercritical boilers and increasing unit size to 660-800MW; aiming for roughly 40% efficiency for each unit.
>
> 8) Plans for Ultra Mega Power Projects with ultra-supercritical units, each 4000MW; 3 UMPP projects already awarded construction contracts through competitive bidding process; all based on imported coal.
>
> 9) Currently, roughly 63,000MW of new plant capacity under construction (includes UMPPs)

The newer base power plant options discussed above, which are also initiatives listed in the NAPCC (e.g. supercritical technology, IGCC and UMPPs) all have the potential to be adapted for CO_2 capture technologies. However, the Indian power sector was not in favour of CCS because it reduces power plant efficiency, and also the safety of CO_2 storage was not considered to have been demonstrated at scale (Interview B9 2008). Furthermore, it was considered to be a very expensive option, and additionally a very risky endeavour with no benefit for the people (Interview B9 2008). Below, some of the newer base power plant options are explored further, which India was considering during the period of fieldwork (2007-2010), highlighting the specific challenges for each option in terms of CO_2 capture.

Supercritical power plants:

Supercritical[90] power plants heat steam to higher temperatures, which allow higher plant efficiencies to be obtained and this type of power plant is considered a good fit with post-combustion capture technology (see Section 4.2.1). Also, research by Chikkatur et al. (2009) shows that supercritical technology is suitable to Indian conditions, partly because a number of plants have already been built worldwide, and so the technology can be considered proven. Supercritical power plants were introduced in India starting with the Mundra power plant in the state of Gujarat, which has a 660 MW unit, and became operational in 2010 (Adani 2011). Notably, this particular power plant was set up as a CDM project through the UNFCCC (UNFCCC 2010), indicating strong international dimensions, in terms of technology transfer and knowledge exchange. However, the decision to accept the Mundra project as a CDM project, which was made in Copenhagen by the CDM Executive Board at COP15 in 2009, was thought to be controversial by NGOs because *inter alia*, coal-fired power was considered to be against the sustainable development criteria of the CDM framework (Field notes, Copenhagen, 16 December 2009; also see CMW 2013). Moreover, at the same time, CCS had yet to be accepted under the CDM framework, which was also a contentious subject at the international climate negotiations (see Section 6.3). This is connected with the discussion in Chapter Six, regarding India's stance on CCS, i.e. there were no co-benefits associated with implementing such expensive and untried

[90]Supercritical in this context describes the thermodynamic state of the steam that drives the turbine, i.e. there is no clear change of state between the liquid and gaseous phase. This is achieved when the fluid is above its critical temperature and critical pressure, see: http://www1.chem.leeds.ac.uk//People/CMR/whatarescf.html

technology, nor does India feel obliged to cut its CO_2 emissions due to development priorities.

Furthermore, even though coal washing (see Section 5.3), a process whereby impurities and ash can be removed, may be increasingly important to minimise the risks of boiler damage associated with burning poor quality Indian coals, concerns still remain that it may not be technically feasible to move to advanced supercritical steam conditions (Chikkatur and Sagar 2009). Therefore, in the future if India were to consider retrofitting CCS technology, it may be more appropriate to consider those supercritical power stations that are being planned on the basis of imported coal, such as the Mundra power plant and other coastal projects. Notably, imported coal will depend upon security of supply from other coal-rich nations, which hinges upon strong international cooperation and good political relations.

Integrated gasification combined cycle (IGCC):

As described in Section 4.2.1, IGCC plants gasify coal instead of combusting it and the syngas (a mixture of carbon monoxide and hydrogen) produced by gasification is then burned in a combined cycle power plant. This type of plant is typically associated with pre-combustion capture technology.

So far, there has been very limited global deployment of IGCC, partly due to the relatively high costs of IGCC compared to pulverised coal plants when CO_2 capture is not required. It is likely, therefore, that different technologies will be better suited to particular sites depending on a number of local factors. As noted by Ockwell et al. (2008) and Chikkatur et al. (2009), many Indian coals cannot use the most common gasification process (slagging entrained-flow) due to high ash content and high ash fusion temperatures. Therefore it is likely that Indian coals will favour the continued use of pulverised coal power plants for providing electricity from coal, even if CO_2 capture is used. For these reasons, the study by Ockwell et al. (2008), which looked specifically at IGCC technology transfer in an Indian context, recommended that indigenous R&D was crucial, and “possibly full-scale demonstration would be required before commercial plants would be viable” (Ockwell et al. 2008, p4113). Although other gasification options with greater circulation of solids may be appropriate, they were not yet considered commercial at the time of the research (2007-2010). Fluidised bed gasifiers are considered to be most appropriate for Indian coals and could potentially be adapted to include CO_2 capture (Chikkatur et al. 2009). During the study period, Bharat Heavy Electricals Ltd. (BHEL), India's largest power plant equipment manufacturer, was testing a small-scale unit (6.2 MW) based on Indian coal, and a few independent experts that have studied BHEL's gasifier "were quite positive about its potential viability" (Ockwell et al. 2008, p. 4111).

With IGCC technology, India is actively participating in the early stages of technology development, i.e. directly involved in how the technology is defined. This is because IGCC technology developed so far in developed countries is using better quality coals; high-ash coals are not suitable for these forms of IGCC plants. Therefore, the interviewee from India's National Thermal Power Corporation (NTPC) (Interview B9 2008) opined that the shortcomings of pre-combustion technologies were connected with loss of efficiency, again, related to the quality of India's coal. Though he felt that the more India was involved with research specific to Indian coal conditions then the more likely India would be willing to adopt the technology (*Ibid.*). Therefore, in this context, India has to play a significant role in shaping the technology, especially due to the unique conditions set by Indian coal. However, it should be noted that hydrogen is a by-product of this process, and all interviewees representing the power sector (Interview B1 2008; Interview B9 2008; Interview B10 2008) indicated that this was the key motivation behind Indian interests in IGCC. In this context, CCS is viewed in terms of its co-benefits, rather than just climate mitigation, demonstrating its mixed identity.

Ultra Mega Power Plants (UMPPs):

The discussion above explains India's interest in these very large power stations, which have a generating capacity of 4GW per site and are based on ultra-supercritical[91] technology. Given India's need to develop newer and more efficient power plants, in

[91] What differentiates UMPPs from the supercritical technology discussed earlier is not only their substantial size and generating capacity, but also that both supercritical and ultra-supercritical boilers operate at such high temperatures and pressures that special materials and alloys are needed for boiler tubes and turbine blades.

2008, the UK Foreign and Commonwealth Office (FCO) commissioned a study, conducted by British engineering firm Mott MacDonald (MottMac). As a result, two reports were produced, one looked at the risks of moving to more advanced steam conditions for the UMPP projects (MottMac 2008a), and the other explored the potential for making UMMPs CO_2 Capture-Ready (CCR)[92], with the intention of making CCS retrofit less challenging if in the future India was in a position to retrofit this type of power plant for CCS technology (MottMac 2008b).

There are two things to note regarding these reports. Firstly, the UK Government commissioned these technical reports, even though by 2008 the Indian State had made its stance on CCS technology quite clear, especially in the UNFCCC forum, i.e. that it opposed any form of implementation in India (see Chapter 6). Furthermore, the expertise employed was from a British engineering firm, with an established R&D base in the UK. Given the strong commercial drivers highlighted in previous chapters, my research clearly revealed that the MottMac studies were primarily discovering relevant opportunities for UK industry. Moreover, the MottMac analysis was not endorsed by the Indian Government, and key Indian decision makers, such as the Chairman of India's Planning Commission, the Minister of Science & Technology and the Director of Technology at the Ministry of Power felt that the UK was forcing their particular brand of CCS technology on to India (Interview A1 2008; Interview B1 2008; Interview B6 2008). Additionally, the representative of India's Planning Commission expressed his suspicions about a technology that had yet to be demonstrated in the UK, and so, he questioned the reasons why the UK Government were intent on selling India an "untried and untested" technology (Interview B6 2008). This interviewee was adamant that he didn't want India to be used as "a guinea pig" for CCS, likening it with the Bhopal disaster, and did not want foreign firms to exploit India under the guise of climate mitigation (*Ibid.*). Similarly, the representative from the Ministry of Science and

[92] The MottMac study (2008b) study used an approach for capture readiness that was originally proposed by the IEAGHG (2007), and which has now been incorporated into UK carbon capture ready (CCR) regulations under section 36 of the Electricity Act 1989 (see UK DECC 2009b). This involves a comprehensive but flexible set of assessments of a new plant design to ensure that avoidable barriers to the retrofit of CCS are minimised. Almost all of the modifications identified in the IEAGHG CCR method can be summarised as identifying and leaving 'intelligent space'.

Technology also questioned which State stood to gain more if CCS were demonstrated or deployed in India, mentioning that the IP is likely to remain with foreign firms (Interview A1 2008). Interestingly, this situation presents a conundrum in terms of CCS technology transfer. On one hand, the Indian Government would like CCS to be proven elsewhere before it considers it a possibility, while on the other hand the state wants to be involved with innovation and R&D processes in order to enhance its own capabilities. Therefore, this situation is best described through technological political realism, where inter-state relations are defined by competition over power and influence, demonstrating the political consequences associated with the mixed identity of CCS: India perceived it as a commercial project in UK's favour, rather than a genuine option for mitigating climate change.

Secondly, there are strong links with the international climate dialogue discussed in Chapter Six. The MottMac reports were published in 2008, when the CCS-CDM dialogue was at its peak, and it is evident that the CDM was a key driver behind the commissioning of these reports, showing that CCS technology is inherently bound with international political relations. For example, in the first (risk analysis) report, the three main categories of risks identified were: plant performance under Indian conditions, economic viability of advanced technologies, and the level of support offered by the potential value of Certified Emissions Reductions (CERs) that might be available within the CDM. This report concluded that:

> *"..there are small differences between all technology options with low supercritical appearing the most attractive investment at all CER values for Indian coal and up to around US$20 per CER for plants firing international coal." (MottMac 2008a, p. xiii)*

This connection to CERs is understandable because there was no other financial incentive for carbon abatement at the time, other than the EU Carbon Market and the EU Emissions Trading Scheme. Given the expense of CCS technology, CERs became even more important for financing potential CCS projects in developing countries, as it was the only financial mechanism available for climate mitigation projects. The interviewee from India's Power Finance Corporation (PFC) stressed that it was critical for there to be some form of financial incentive to capture CO_2 in India, carbon abatement on its own was not enough (Interview B10 2008). This stance is aligned with India's overall approach to climate change and the need for co-benefits, as discussed in Chapter Six. In addition, the interviewee mentioned the historical responsibility of the West, and therefore the need for developed countries to cover costs of mitigation, particularly as CCS did not benefit the people of India (*Ibid.*). This sentiment was also emphasised in the stakeholder survey, where the majority of respondents were of the opinion that developed country governments were the most important group that should contribute to training and financing of CCS, both in terms of initial projects and overall wider deployment (Survey 2009, Appendix A & B). Developed country private industry was ranked as the second most important group that should contribute to CCS implementation (*Ibid.*), indicating also that the State's role supersedes that of private industry. Therefore, this further demonstrates the importance of inter-state political decisions on CCS technology transfer.

In regards to the second report on CCR method as applied to Indian UMPPs (MottMac 2008b), again, the analysis is contextualised in terms of a 'global carbon market':

> *"The concept of CO_2 'capture-ready' plant is to design new-build generation plants without CCS, while facilitating later retrofit of CCS to avoid the lock-in of CO_2 emissions from these plants caused by technical or economic cost barriers once the capture technology itself has matured. This approach can imply low upfront costs and unimpaired performance, but maintains the flexibility to later retrofit CCS to the efficient coal plants being built today in India – when the improved CO_2 capture technology maturity and the regulatory environment, including principally the expected commercial opportunities from the global carbon market, make this attractive to plant owners." (MottMac 2008b, p. S-3)*

Based on this approach, plant capital requirements are reported to be increased by no more than 1% for the essential design changes required for a typical UMPP to be capture-ready. Under the CO_2 price scenarios assumed, it is also suggested that capture-readiness "would be a commercially attractive proposition" since it is valuable for plants to have the option to retrofit CO_2 capture at minimal, although still significant, cost in the future (*Ibid.*).

Moreover, one of the more significant aspects of developing capture-ready projects can be in determining what measures should be required to show that any CO_2 captured at a particular site will be able to access a suitable storage site. Within the Mott MacDonald study, it is assumed that:

> *"The definition of 'capture-ready' should also encompass the transport and storage of CO_2. Preliminary confirmation of feasible routes to CO_2 storage should be undertaken, with the planning horizon and any required regulatory changes, to overcome current barriers, understood prior to generation plant construction." (MottMac 2008b, p. S-5)*

At the time of the study, nine UMPP sites[93] had been identified: three coastal sites using international coals and six inland sites using Indian coal and located at the pit-head (open-cast mine). It was concluded that CO_2 capture could be economically viable for all sites under the CO_2 price scenarios considered, although expected costs could be around \$5/tCO_2 higher for the inland sites when compared to coastal sites, mostly due to increased transport distances for CO_2 storage. Out of the nine sites that were assessed, the three most favourable were all coastal plants; Kirshnapatnam (Andhra Pradesh), Cheyyur (Tamil Nadu) and Girye (Maharashtra) were considered to be the best sites in terms of least expensive[94] options for CO_2 emission abatement using CCS (including CO_2 transport and storage) (MottMac 2008b, p. S-6). At the time, out of these three sites, Krishnapatnum was the only one with contracts awarded for construction.

Moreover, it should be noted that successful deployment of CCS projects in any jurisdiction would require that adequate project *finance* could be obtained. Making the case for project finance requires a number of factors in addition to cost to be taken into account. For example, uncertainty associated with any incentives for reducing CO_2 emissions are likely to lead to project financiers requiring that CO_2 prices are higher

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[93] This has risen to sixteen (see Chapter 4).

[94] The calculated cost was "approximately USD 33/tCO_2, primarily due to their location close to potential CO_2 sinks. These three sites also do not require any significant overland transport of CO_2 to the identified storage reservoirs, which may offer reduced regulatory and planning barriers relative to the remaining six UMPPs" (MottMac 2008b, p. S-6).

than implied by only cost considerations for CCS projects to proceed, at least in the short to medium term. As a result, the study concluded, based on projected improvements in post-combustion CCS technology[95], that a retrofit date in 2020 or beyond would be appropriate for Indian UMPPs, where it is "likely to increase the likelihood of an adequate incentive being available to abate greenhouse gas emissions" (MottMac 2008b, p. S-7).

Finally, in the context of UMPPs, there is the issue of size, and the need for additional land to build a CO_2 capture facility at a power plant. This has implications for the acquisition of land. Given the discussion in sub-section 7.2.1, there is already a high security risk associated with the UMPPs planned as pit-head projects, as these are based in close proximity to the existing coal mines, in those very locations with high occurrences of insurgency attacks.

7.2.3 Storage in the Indian context

For CCS technology to be applicable for mitigation, it is of course, necessary to identify suitable locations for safe, long-term storage of CO_2. As discussed in Chapter Four, the permanent storage of CO_2 is generally expected to involve the injection of CO_2 into suitable formations in large sedimentary basins. Therefore, a detailed assessment of the storage potential, both in terms of quantity and integrity, is required for potential storage sites such as coal fields, oil and gas fields, and deep saline water-bearing reservoir rocks. The analysis in this section reviews whether there are suitable geological formations available for CO_2 storage in the Indian subcontinent.

At present, there is limited knowledge in this field due to a general dearth of essential data required to characterise geological sites. Nevertheless, preliminary studies indicate that potential storage sites on the subcontinent are located in the Gangetic (north, northeast), Brahmaputra (northeast, Bangladesh border) and Indus (northwest, Pakistan border) river plains, and along the immediate offshore regions on the Arabian Sea (southwest coast) and Bay of Bengal (southeast coast) (IEAGHG 2008).

[95] Projected in IEAGHG (2007) study.

Locations of these sites in relation to India's current largest point sources of carbon dioxide emissions, as well as hydrocarbon fields are illustrated in Figure 7.1. Also, the storage basins are differentiated according to their storage potential, where the pink basins are those considered most suitable.

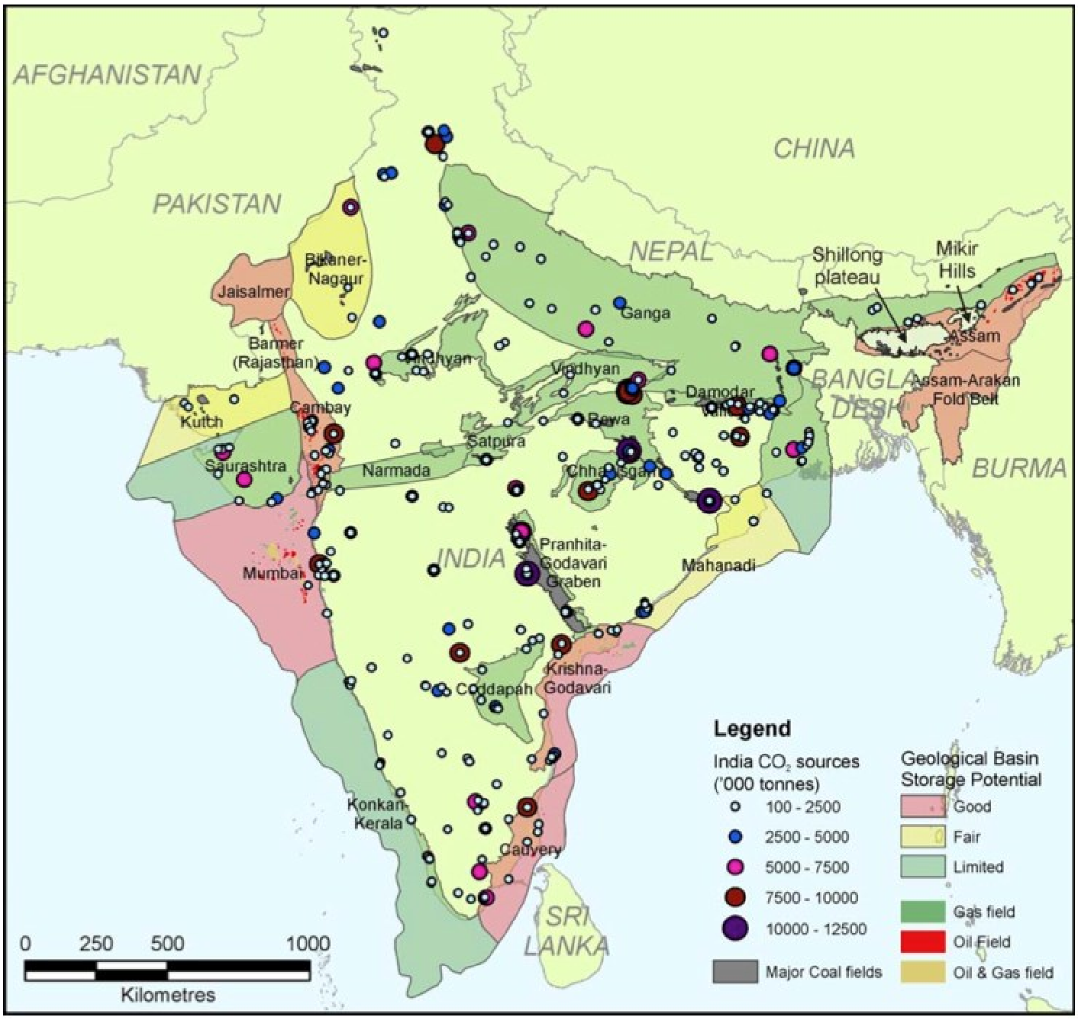
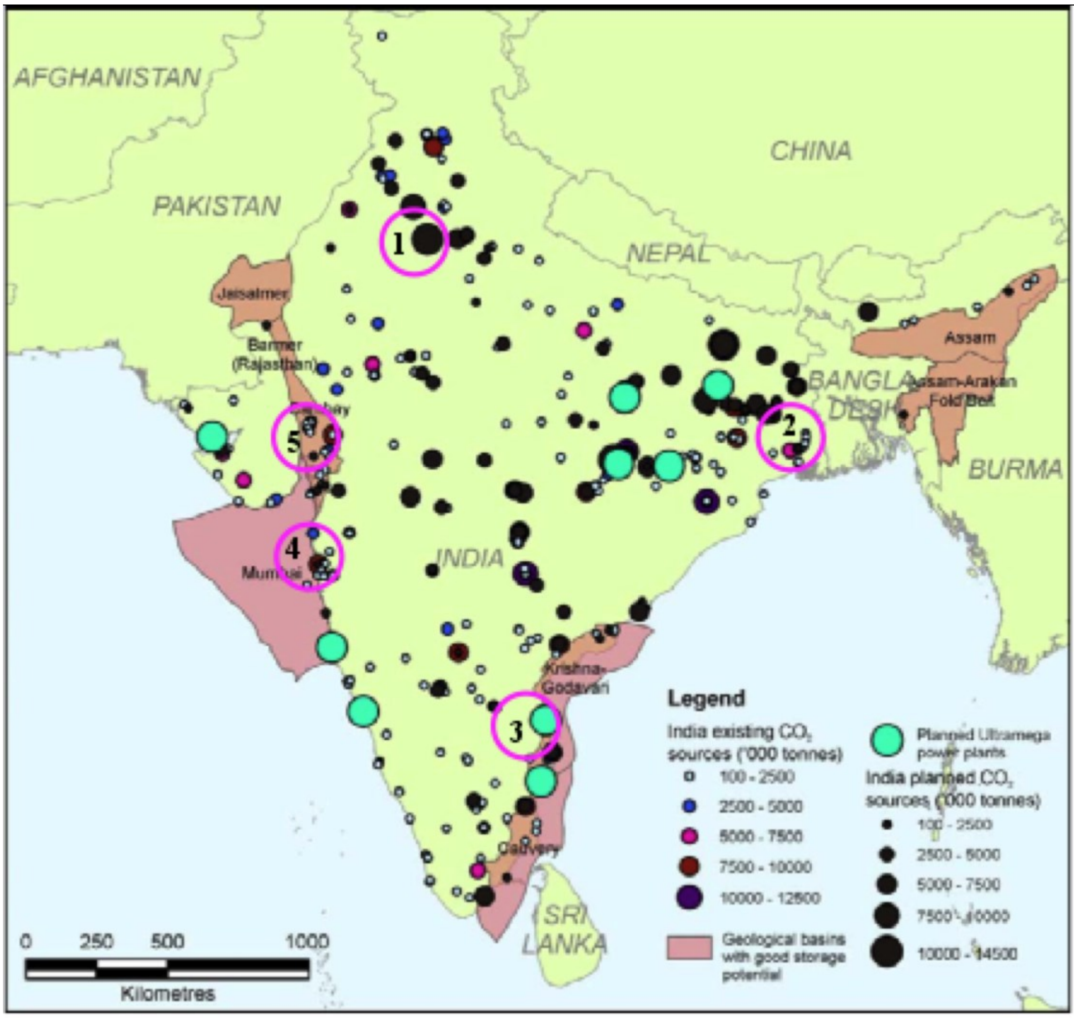


Figure 7.1: Current CO_2 sources and oil and gas fields in India with potential CO_2 storage sites (source: IEAGHG 2008).

Initial attempts at evaluating the storage potential in India were made by Singh (2006), estimating that roughly 5 Gt CO_2 could be stored in unmineable coal seams, 7 Gt CO_2 in depleted oil and gas reservoirs, 360 Gt CO_2 in offshore and onshore deep saline aquifers, and 200 Gt CO_2 via rapid mineralization into calcite and magnesite in basalt rocks. The latter estimate refers to laboratory experiments conducted by McGrail et al. (2006) that demonstrated a relatively rapid chemical reaction of CO_2-saturated pore water with basalts to form stable carbonate minerals. This analysis presents CCS opportunity for India as a very extensive portion of the central peninsula consists of one of the world's largest basalt lava flows known as the Deccan trap formation. As a result, there is ongoing collaborative research taking place in this area between India's National Geophysical Research Institute (NGRI) and the USA's Pacific Northwest National Laboratory (PNNL), under the auspices of the CSLF. However, this concept is still in the experimental phase and can only be considered a possibility if the basalt is adequately permeable to the CO_2 and can be demonstrated to be safe (Schaef et al. 2009). Furthermore, storage of CO_2 in basalts at the commercial scale may be decades into the future, therefore not considered relevant in terms of early deployment.

A study conducted for the IEA Greenhouse Gas R&D Programme (IEAGHG 2008) by the British Geological Survey has revised down the estimates that were first made by Singh et al. (2006). The authors still conclude that there may be significant CO_2 storage potential "in the oil and gas-bearing sedimentary basins around the margins of the peninsula, especially in the offshore basins, but also onshore in the states of Gujarat and Rajasthan" (IEAGHG 2008, p. 2). It should be noted, however, that the sites considered to have the best potential are not well placed in respect to major CO_2 sources occurring in the central parts of the peninsula, such as Delhi or Calcutta (see Figure 7.2). However, in terms of other major urban centres, some of the potentially good storage sites are located near Mumbai, Ahmadabad and Chennai. In addition, the locations of some of the planned UMPP projects, in relation to sites potentially suitable for CO_2 storage, are also shown in Figure 7.2.



[redacted]
sources in India, plus the location of major cities (Delhi [1]; Calcutta [2]; Chennai [3]; Mumbai [4]; Ahmedabad [5]) (base map: IEAGHG 2008).

The 2008 BGS assessment of potential for geological storage in India suggested that CO_2 storage in coal seams is likely to be constrained since these coal reserves can be easily mined and used as fuel (IEAGHG 2008). Taking this into consideration, the calculated storage potential countrywide was found to be more of the order of 345 Mt CO_2 in the major coalfields, where none have the capacity to store more than 100 Mt CO_2, and only eight of the fields can store more than 10 Mt CO_2 (*Ibid.*).

For oil and gas reservoirs, the authors calculated the total storage capacity to be between 3.7 and 4.6 Gt CO_2. Furthermore, the authors noted that only a few fields, such as the Bombay High field and offshore Mumbai, are thought to have ample storage for the lifetime emissions of a medium sized coal-fired power plant, although it is technically feasible for one capture plant to use multiple storage sites during its lifetime. None of the fields, it would seem, are large enough to store the lifetime emissions of India's planned UMPPs (currently estimated each to produce 28-29 Mt CO_2/year for a period of 35 years, or roughly 1 Gt CO_2 in total for each UMPP).

However, the IEAGHG report did not assess the potential of deep saline aquifers. Even though Singh et al. (2006) estimate a storage potential of roughly 360 Gt CO_2 for saline aquifers, a recent analysis by the IEA assumes that only one-sixth of that could potentially be available for storage (IEA 2011c). Subsequently, in their analysis the total potential storage capacity would be limited to roughly 65 Gt CO_2 for India, which includes depleted oil and gas fields, unmineable coal seams and saline aquifers, illustrated in Figure 7.3 (IEA 2011c, p. 30). The theoretical storage capacities in basalts are also shown in Figure 7.3.

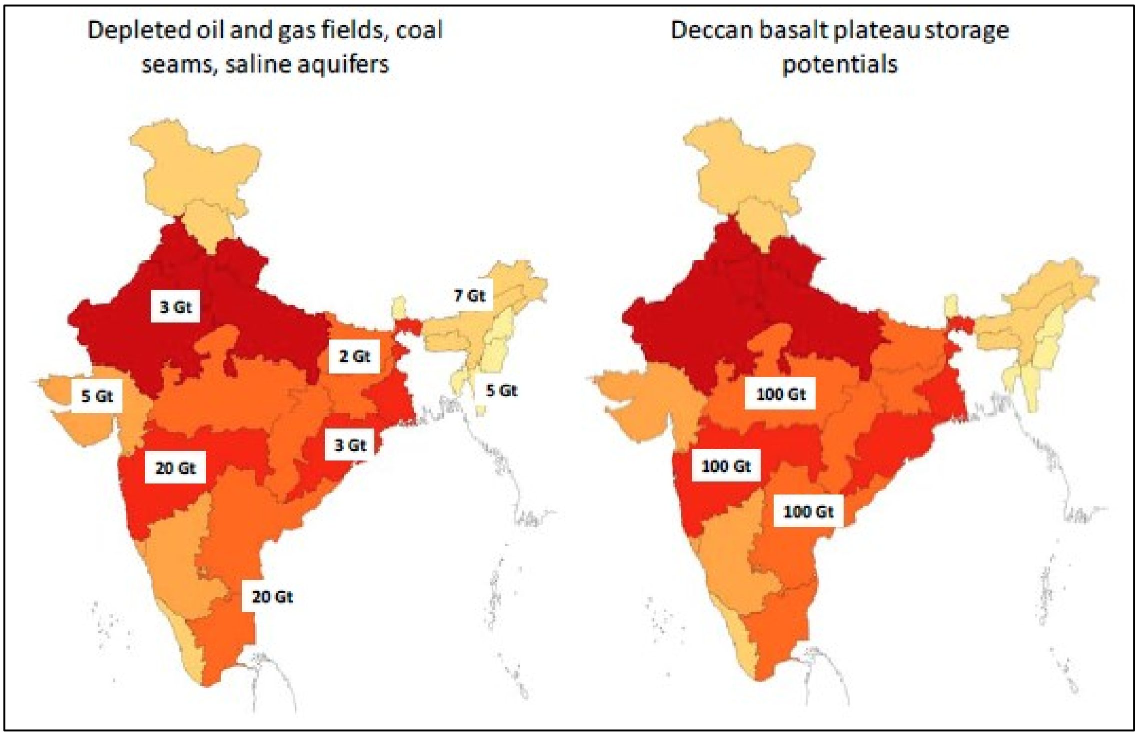


Figure 7.3: Regional distribution of CO2 storage potential estimates in sedimentary basins and basalt formations in India (source: IEA 2011c).

Some areas in the northeast, such as Assam, are thought to have reasonable CO_2 storage potential, although this region is quite distant from the main emission sources, requiring thousands of kilometres of pipeline infrastructure, typically costed at $1M per km (MottMac 2008b). In addition, the most direct pipeline route passes through Bangladesh and significant increases in pipeline length would be required to avoid crossing Bangladesh. It should also be noted that even though the Indo-Gangetic plain, that lies in China, Nepal, India and Bangladesh, with the largest portion in India, has significant technical potential for storage, it has been classed as 'limited' by the authors of IEAGHG (2008), (green area in Figure 7.1). This is due to public acceptance concerns over possible conflict between multiple uses of land since this area is drained by several rivers and is, therefore, an extremely fertile region with over 580,000 square km of arable land that supports a population close to half a billion. This region represents India's agricultural heartland, and it is considered to be one of the "bread-baskets" that feed the world (UNDP 2007/2008).

Furthermore, although it has not been discussed in detail in the literature, the implications of seismic activity in parts of India also need to be taken into consideration for any assessment of storage capacity. An expert from India's Planning Commission expressed concern over injecting CO_2 in earthquake-prone areas, such as the North-Eastern regions (e.g. the state of Assam, which is considered to be suitable for CO2 storage in Figure 7.2) (Interview B6 2008).

Given the geological limitations discussed here, the prospects for CCS implementation in India are best in the offshore storage areas that are located near major cities and industrial corridors. The analysis below discusses these strategic areas and explores the options for shipping CO_2 to other regions.

7.2.4 Transport in the Indian context

As emphasised in the Mott Macdonald report (MottMac 2008b), any 'capture-ready' design must include transport and storage. This study also suggested that coastal plants are likely to be favoured as locations for capture-ready power plants. One reason for this is that there is very limited transport infrastructure on land. In order to meet the demands of new power stations, a substantial increase in rail capacity for coal transport will be required, and therefore new-build plants are preferred to be near port facilities or at the mine itself (IEA 2011c). This however, will also mean more investments in the transmission grid to distribute electricity to the main demand centres (*Ibid.*).

In terms of CCS, existing pipeline infrastructure is located primarily in the northwest, in the industrial corridor between Mumbai and Delhi, via Gujarat. However, India is expanding its port infrastructure[96], not only to support the UMPPs relying on imported coal, but also because there is a well established LNG and LPG trade with the Middle East, and India has become the principal hub for refined petroleum products, where the largest and most established refineries are on the coast (e.g. Jamnagar, Mumbai, Kochi, Vishakapatnum and Chennai). Therefore, shipping of CO_2 may be the most cost-effective transport option for a prospective CCS project, as suitable storage in India is largely offshore.

Furthermore, given that India has limited CO_2 storage to match projected CO_2 emissions, then, one option may be to capture CO_2 emissions from large industrial areas in India and export them to be used for EOR purposes in other regions that also have far more storage potential, e.g. the Middle East. States such as Qatar are dominant gas producers with established LPG tanker traffic, and so these tankers could essentially be converted to take return loads of CO_2 for injection into depleted gas or heavy oil fields (see discussion in Section 4.2.2). The potential of this option is explored further here through the case study on the Cambay basin in North West India.

[96] During the study period, India had two LNG import terminals on the western coast, in Dahej and Hazira. A third terminal became operational in December 2010 (Dabhol-Ratnagiri), and a fourth terminal was currently under construction at Kochi on the south west coast (IEA 2011c).

7.3 Case study: Cambay Basin (Gujarat)

This section provides a detailed analysis of a case study on the Cambay basin area, based in the state of Gujarat. This region, from a technical perspective, has the potential to be a suitable place for early deployment of CCS technologies. However, as discussed throughout this thesis, from the outset the Indian Government has had reservations about CCS implementation in India for climate change mitigation purposes, for political reasons (see Chapter Six) as well as due to technical challenges (see Section 7.2.2 and 7.2.3). The aim of this case study is to further demonstrate, that despite the Cambay Basin having geographical/technical favourable conditions for early deployment of CCS, there were social and political factors that prevented CCS technology transfer and implementation from occurring. It should be noted that the shipping and offshore scenarios discussed in this section are hypothetical and based largely upon exploratory discussions with interviewees or insights from the stakeholder survey.

7.3.1 Case Study Selection

As discussed in Section 7.2.2, new coastal-based power stations were highlighted as being suitable entry points for CCS technology transfer in the period 2007-10. It is also possible that the transport of CO_2 by ship to other regions with suitable storage has the potential to be a cost-competitive option for CCS projects (see Aspelund et al. 2006). Furthermore, there is clustering of major CO_2 sources in India (including major industrial sites as well as power plants), and also areas where a number of power plants are located in close proximity to coal reserves. These large CO_2 clusters are highlighted in Figure 7.4.

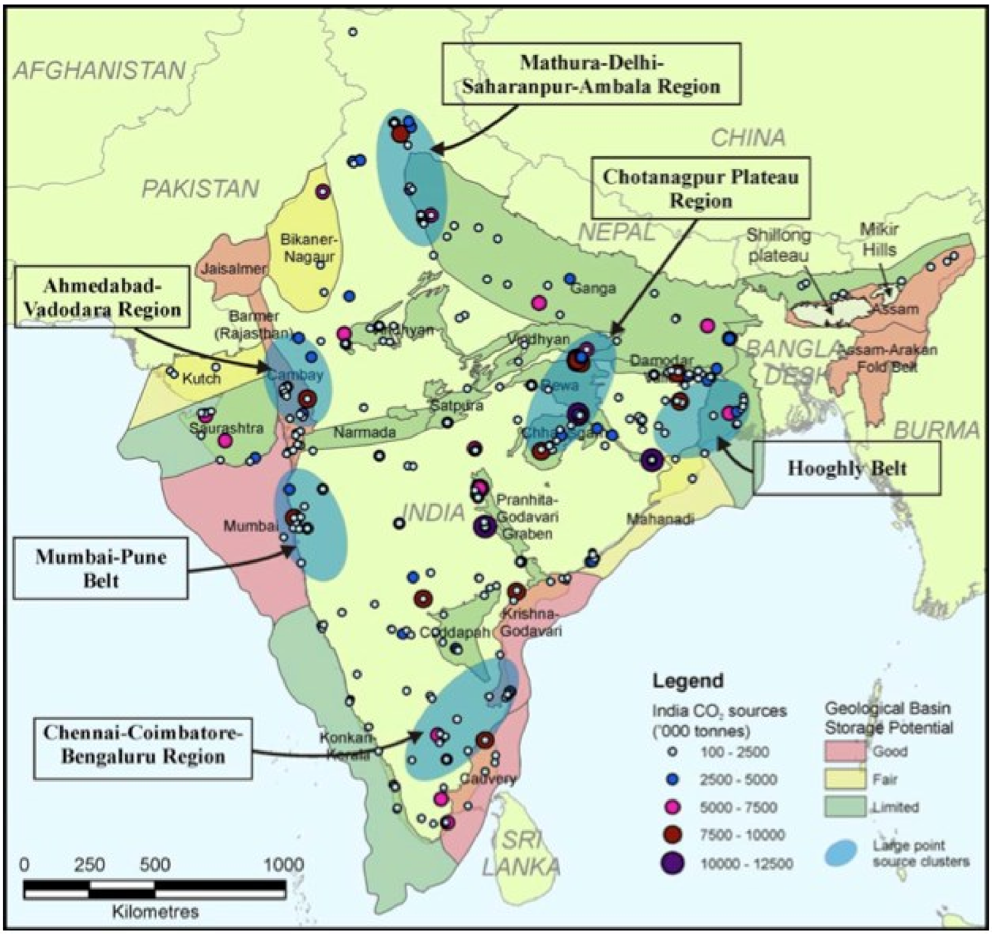


Figure 7.4: Existing CO_2 sources grouped into industrial clusters and geological basins with CO_2 storage potential. The Cambay basin is at the core of the Ahmedabad – Vadodara industrial belt (source: IEAGHG 2008).

The UK and Europe have been considering the potential to take advantage of such clusters to minimise CO_2 transport costs by using a shared infrastructure for long distance pipelines (see Element Energy 2007). If India decides in the future to implement CCS technologies, then the cluster or 'hub' approach was considered useful for determining suitable areas for potential CCS technology transfer.

In Figure 7.4, six clusters of major CO_2 sources (blue ovals) have been emphasised over the geological storage potential of the Indian sub-continent. Notably, Figure 7.4 illustrates that half of the clusters are located over areas with limited storage capacity. The remaining clusters that are in close proximity to geological basins identified as having good storage potential are in coastal areas (see Figure 7.4). Using this method, i.e. matching CO_2 sources with suitable storage sites, three candidate areas to be used as a case study, or a site with suitable conditions for early deployment, can be identified. Table 7.2 shows how these three areas perform against the selection criteria below:

- *Proximity to good geological storage site* – based on assessments from IEAGHG's 2008 geological survey of the sub-continent; presence of numerous oil and gas fields; there is good potential for EOR in the area.

- *Fixed or potentially fixed project (e.g. UMPP)* – the area already has an established industrial corridor and the necessary infrastructure for CCS technologies (e.g. pipelines, new-build power plants etc.); it is also one of the major point sources for CO_2 emissions in India (e.g. world's largest refinery is located in Cambay area).

- *In a politically stable area* – this has implications for access and general safety whilst doing fieldwork, particularly if there is an opportunity for a site visit.

- *Established contacts* – informants, who were either already working in the area, or provided linkages with further contacts, which were made during the first field trip in Jan-Mar 2008 (see Chapter 3).

Table 7.2: Candidate areas for case study options against selection criteria

	Criteria			
Candidate Area	Proximity to good geological storage site	Fixed or potentially fixed project (e.g. UMPP)	Politically stable area	Established contacts
Ahmedabad-Vadodara Region	Yes; Cambay Basin	Yes	Yes	Yes
Mumbai-Pune Belt	Yes; Mumbai High	Yes	Yes	No
Chennai-Coimbatore-Bengaluru Region	Yes; Cauvery & Krishna Godavari (KG) Basins	Yes	Yes	No

A crucial aspect of the selection criteria was the need for contacts, who could assist with access to data and/or also had an interest in the prospects of CCS technology in India. These individuals were largely from private industry.

The Cambay basin, which is located in the state of Gujarat (Ahmadabad – Vadodra region in Figure 7.4), was the only region that met all the criteria outlined in Table 7.2, and so was selected for a detailed case study.

The state of Gujarat is considered to be one of the more industrialised states in India, and is also more politically stable, in comparison to the coal-rich states in the East[97] (see Section 7.2.1). At the time of this study, Gujarat was ranked fifth in terms of Foreign Direct Investment (FDI) inflows to India, which were valued to be more than $1 billion dollars in the 2011-12 fiscal year (Khanna 2012). In comparison, the state of Maharashtra (the Mumbai-Pune belt in Figure 7.4), was the top state for foreign investment, worth over $9.5 billion this past fiscal year (*Ibid.*). According to the Indo-American Chamber of Commerce, the key industries that attract FDIs and joint ventures are, *inter alia*, the oil and gas sector as well as infrastructure industries. Gujarat is very rich in limestone, and is the leading producer of cement and soda ash in the country. Some of the reasons why Gujarat is popular for FDI include an extensive network of rail and good roads, along with the highest number of airports in the country (IACC 2010). These are all indicators of the relevant infrastructure required for a prospective CCS chain. Therefore, with these characteristics, combined with the established contacts, the Cambay basin became the case study of choice.

The case study draws upon on interviews with technical experts from the oil and gas sectors, as well as professionals from the shipping industry and security services. All interviewees, in the period 2008-2010 were either actively working in the Cambay area, or had experience of working in that area. A map of the region, with the relevant industrial infrastructure is depicted in Figure 7.5.

[97] Compared to the threat of Maoist insurgency attacks Gujarat is relatively safer. However, in the recent past Gujarat suffered from fierce communal violence in 2002. The Chief Minister at the time was Narendra Modi, a very polarising figure in Indian national politics. He was the Chief Minister of Gujarat during the period of this study (2007-2010), and he had the reputation of being good for business development and FDIs.

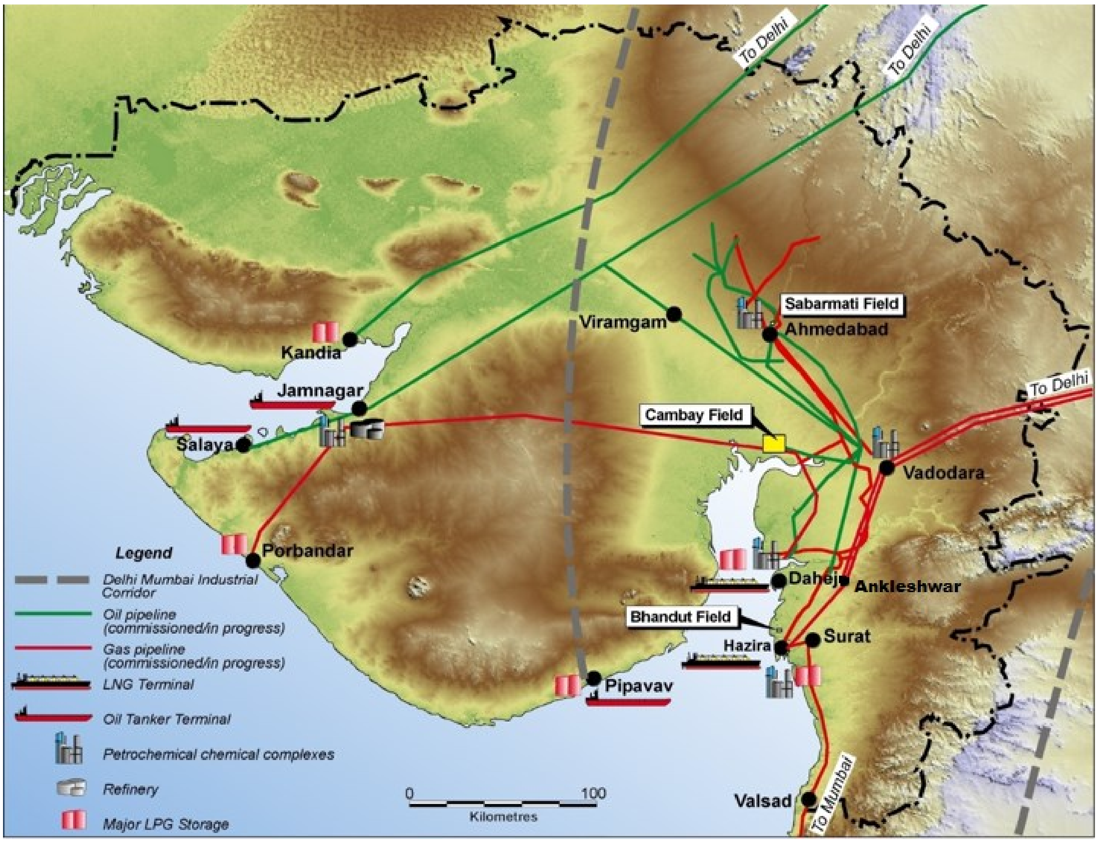


Figure 7.5: The industrial infrastructure surrounding the Cambay basin in the state of Gujarat. Source: Oilex Ltd. (www.oilex.com.au).

Figure 7.5 shows the Cambay basin area, which is partly offshore, though predominantly onshore (also see Figure 7.4), and one of the active hydrocarbon fields within the basin is labelled as a yellow box in Figure 7.5. Notably, there are established refineries (including Asia's largest, see Section 5.3.3) and other industries in the region. Due to the large amount of industrial operations in the Cambay region, there are existing pipeline networks as well as shipping terminals for LPG and LNG tankers. As discussed in Chapter Four and Chapter Five, these are all features of other technological systems that have the potential to be integrated into a future CCS system (see Figure 4.7). Given the mixed identity and flexibility of CCS technology, the Cambay basin becomes a useful starting point for future implementation. For example, there are infrastructural elements, such as newly built supercritical power plants, shipping docks designed for gas-transportation, combined with the geology being well-characterised by an established hydrocarbon industry, all of which could be incorporated into a CCS system. Furthermore, the area hosts a range of carbon-intense industries, such as cement and steel production, which also have the potential to be integrated into a CCS technological system. Consequently, there is already a great deal of international technology transfer taking place in this region, mainly via joint ventures between MNCs and state-owned operators in the region. The following sections further examine such operations, highlighting the sociotechnical aspects that, despite the favourable context, prevented CCS implementation during the study period.

7.3.2 CO_2-EOR activities in the region: The Ankaleshwar/Hazira project

The Oil and Natural Gas Corporation (ONGC) of India is a state-run enterprise and is the main operator in the Cambay area. As discussed in Chapter Four, one pathway for a CCS chain could involve Enhanced Oil Recovery (EOR), which involves CO_2 injection for oil extraction (see Section 4.2.3 & Figure 4.5). At the time of this study, there was interest in CCS-EOR from ONGC, and initially there had been demonstration of political support for such an endeavour (see Section 6.2.2). However, within a few months the Indian Government had a change of heart, and the focus of this section is the Ankaleshwar/Hazira project, which was central to the political turn-around. This section mainly draws upon an in-depth interview with a representative from ONGC, who was directly involved with the project.

The Ankaleshwar/Hazira project currently receives acid gas[98] at the Hazira plant (Fig 7.5) from the Mumbai High offshore fields (Figure 7.4), where the H_2S is extracted using a Sulphur recovery unit (SRU) and then CO_2 is released into the atmosphere. The volume of CO_2 released at Hazira exceeds 600,000 SCM[99]/day, and the ONGC believed that setting up an EOR capability at a mature field, Ankaleshwar (Figure 7.5), could put this gas to an alternative use (Interview B4 2008). The injection being considered was at a depth of 1800-2200 m, which is a suitable depth range for CO_2 storage (see Section 4.2.3 and Holloway 2001). ONGC's in-house research on this EOR project had shown that, due to the age and present condition of wells in the Ankaleshwar field, they would

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[98] Natural gas + H_2S + CO_2

[99] Standard Cubic meter.

have to drill a new set of 67 producing wells and 15 injecting wells (Interview B4 2008). Given the high profile of CCS at the UNFCCC during this period, it was thought that CCS-EOR was a good opportunity to attract international investment and cooperation, and potentially carbon credits through the CDM (*Ibid.*).

In February 2008, ONGC signed a memorandum of understanding (MoU)[100] with Norway's StatoilHydro to develop projects on CCS and other carbon management projects, which could be considered for the CDM (see Section 6.2.2). Shortly after the MoU was announced, Statoil started reviewing and analysing the technical details regarding injection in Ankaleshwar, including making recommendations for improving processes that would result in better efficiency and separation in order to capture more CO_2 for EOR (Interview B4 2008). ONGC were interested in capturing CO_2 (approx. 1200 tonnes) from their offshore Hazira facility and transporting it to their onshore field at Ankaleshwar (approx. 70km away), in order to maintain reservoir pressure, rather than use it to decrease the viscosity of the oil (Interview B4 2008; also see Shackley & Verma 2008).

However, by mid-2008 ONGC and StatoilHydro had disagreements on the way the project was heading. Towards the end of 2008, the negotiations had reached a stalemate and the MoU was not revived (Interview B4 2008). According to an ONGC representative, who was involved in the negotiations for the project, StatoilHydro were looking to take advantage of the MoU as a means to gain access to the exploration business in India, which was not well received by India's Ministry of Petroleum and Natural Gas, which essentially regulates ONGC (*Ibid.*). Consequently, ONGC started looking for other partners, because they were still very keen to explore a potential CO_2 market in the region (Interview C1 2008; Interview C2 2008). This is because, in addition to EOR purposes, it was envisioned that excess CO_2 could be sold as feedstock for fertilizer production to the urea production companies, also located in the Cambay area (Interview B4 2008). The ONGC believed that for such projects, the CDM framework would give them a further incentive (*Ibid.*). However, despite dialogue with

[100] This is a document describing bilateral or multilateral agreements between parties, but is not a legally enforceable document, nor does it imply a legal commitment.

other hydrocarbon exploration MNCs that had an interest in CCS in India, without approval from the central Indian Government such joint ventures could not go ahead (Interview C1 2008; Interview C2 2008).

Eventually, towards the end of 2008, the ONGC as well as ONGC Videsh Ltd. (OVL), which deals with international oil and gas exploration, was pressured to stop considering any CCS related projects altogether, either in India or elsewhere (Interview B4 2008; Interview B5 2008). A lead person from ONGC explained that the pressure originally came from the Ministry of Power, which at the time of this study, wielded the most influence out of all energy-related ministries (Interview B4 2008; also see Footnote 85, p. 196). The Ministry of Power felt that all Indian Ministries should have a universal position on CCS and CO_2 mitigation, i.e. in line with the central government position on climate change (discussed in Chapter Six), in the run up to the climate negotiations in Poznan (COP14) (Interview B4 2008). This illustrates the influence of domestic politics, which prevented CCS technology transfer to occur, despite there being interest from industrial sectors. This situation also resonates with Walker's (2000) description of system inertia: circumstances when vested interests want to maintain the status quo and try to resist change.

Notably, it also highlights the commercial interests behind such projects, where CO_2 mitigation is not necessarily the main driver, but rather a positive 'side-effect', which can provide an added income stream. Furthermore, an interviewee from OVL emphasised that the interest in CCS technology was more closely linked to how the CO_2 could be *used*, i.e. it was something of market value (Interview B5 2008). This aspect also highlights how, due to the mixed sociotechnical identity of CCS, it was being interpreted as something other than purely for mitigation purposes (see also Chapters 4).

7.3.3 An overview of CO_2 storage in the Cambay basin

In an interview with a small team of representatives from Cairn Energy India[101], a MNC involved with hydrocarbon exploration and production, it was discussed that the company was exploring the potential for gas storage in the offshore region, within the Gulf of Cambay (Interview C3 2008). Interestingly, the head of reservoir development indicated that they would not consider CO_2 storage within the region unless they had been instructed to do so by the central Indian government (Interview C3 2008). Most of the provisions regarding their operations in the area come through the New Exploration Licensing Policy (NELP) (see Section 5.2.4), and all MNCs operate using Production Sharing Contracts (PSCs). Specifically, PSCs that include EOR or encourage EOR practices, are designed primarily for fast economic recovery. According to the legal adviser to Cairn, if CCS-EOR were to be considered, then the current licensing regime, i.e. NELP, would have to be adjusted because all pore space is under central government control, not the state (Gujarat) government. He further added that if this were the case, then as a result the PSCs with MNCs could include a CO_2 storage provision, but only if that were the ambition of the Indian Government. Notably, the Cairn Energy India team mentioned that ONGC had approached them regarding CO_2 injection, and were also interested in other possible economic resources for capturing CO_2. Interestingly, the petroleum engineer was of the opinion that the current hold back to CO_2-EOR in the area was due to the lack of a good quality source of CO_2 (i.e. with few impurities), as the H_2S separation at Hazira was proving to be technically difficult. It was opined that the capture of a purer stream of CO_2, e.g. captured from a power plant, would perhaps be more useful for EOR. However, it was added that there were no power stations in the area that were considering such technology.

In regards to other nearby hydrocarbon exploration activities, the senior petroleum engineer stated that further inland and heading north towards the Barmer basin (extension of the Cambay, see Figure 7.4), CO_2 injection for EOR would not be advised.

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[101] This included the Head of Reservoir Development (geoscientist), a senior petroleum engineer, and an energy lawyer that dealt with oil and gas Production Sharing Contracts (PSCs) (see table 3.2). These interviews were all held together in December 2008, at the Cairn India head office, located in Gurgaon, India.

This is because the Barmer fields are more suited for chemical EOR, due to the high viscosity of the oil in that region. Towards the southern half of Cambay and heading offshore into the Mumbai fields, the interviewee was of the opinion that this area would be well suited for storage, having more capacity, and being relatively close to the industrial hub in Gujarat and potentially Mumbai as well. However, it was noted that these were carbonate reservoirs, and therefore would require further research in CO_2/water/rock reactions before considering CO_2 injection at a large scale. Furthermore, it was added that very little EOR was taking place anywhere else in Gujarat, and that this was still virgin territory for many companies looking to explore in the region.

Notably, both the head of reservoir development and the petroleum engineer were of the opinion that the area was more likely to be considered for shale gas exploration. This is because the Tarapur shale, which is a regional cap rock that lies over the main reservoir rock, might potentially be rich in gas. If this were the case, then it would have implications for any potential CO_2 storage in the region. In their view, shale gas exploration would likely tamper with the integrity of the seal for any potential storage area, and therefore would not be a suitable site as part of a larger CCS project. It was added that, if gas were discovered, then India would be more likely to exploit that resource first, rather than pursue a climate mitigation option.

As discussed in Section 7.2.3, the Indian sub-continent has limited storage capacity in general, though Cambay was (theoretically) assessed to have good potential by the IEAGHG (2008). However, the findings from the Cairn interviewees indicate that the overall storage capacity in the Cambay basin, particularly at the scale required to match prospective CO_2 outputs from large power stations, e.g. UMPPs, would not be sufficient. They also were of the view that the Indian Government had not shown any interest in CO_2 storage, therefore they would only strictly abide to the terms of PSCs. Only if there was an indication from the Government would they invest in the technical assessment of the region. This presented a major hurdle for CCS implementation in India; storage is a crucial element of the CCS chain, without it there can be no CO_2 mitigation. Therefore, the potential to ship the CO_2 elsewhere, to a more suitable storage location was explored as a way of furthering understanding of the complex international dimensions of CCS, discussed below.

7.3.4 The prospect of shipping CO_2 from India

The idea for exporting captured CO_2 from India to other countries via shipping is a hypothetical aspect of this case study. The idea emerged during the second year of the study period (2008), specifically exploring the potential of CO_2 shipping between India and the Middle East. The concept derives from research indicating that there is greater storage capacity in countries with very large mature oil fields, such as Iran, Iraq, Saudi Arabia and the UAE (see IEA 2010; GCCSI 2011; Masdar 2012). Therefore, CO_2-export to this specific region formed the basis for interviews with individuals from the private shipping industry, which had a commercial interest in CO_2 shipping in general. Given the wider geopolitical dimensions within the Middle East, professionals familiar with this particular trade route were also interviewed to determine the international security risks associated with operating in this region.

According to the representatives from the shipping industry the most significant issue is that CCS demonstration and deployment at a large scale would need to become a reality if CO_2 export via shipping were to become a viable option. This should entail a viable market for CO_2, i.e. there needs to be a significant *demand*, enough for shipping companies to make the investments necessary for designing and building suitable vessels to transport it (Interview C4 2010; Interview C5 2010). Technically it is feasible to design such a tanker (see Section 4.2.2), however, currently there is no market for CO_2 at the scale envisioned (Interview C4 2010; Interview C5 2010). For example, power plants will produce significantly large volumes of CO_2, and so interviewees insisted that there should be a legal and economic incentive to either store it or use it (*Ibid*). The representative from Maersk Group opined that to begin with CO_2 shipping would be most feasible if linked with EOR, as this would require a vessel designed to carry larger volumes (Interview C4 2010). He further added that the economic incentive of oil would be needed because he felt that market mechanisms such as the CDM would not be enough to support a CCS project with a shipping option (*Ibid.*). Interestingly, these responses further illustrate how this particular aspect of the CCS technological system is still at a very nascent stage. This further demonstrates the difficulty in considering CCS as a coherent technological system due to the uncertainty associated with crucial links in a potential CCS chain (in this case, transport).

Furthermore, there are geopolitical dynamics that need to be explored, as there are tensions specific to this particular trade route. Explicitly, CO_2 export via shipping would entail the trans-boundary movement of CO_2, i.e. it will involve multiple jurisdictions, requiring credible national guarantees. Therefore, international cooperation would be compulsory for any such prospective project. However, politically, this will require exceptional diplomacy (Interview B17 2010; Interview B18 2010). Despite being a key importer of hydrocarbons from the Middle East, out of the countries mentioned earlier in this section, India's natural partner in this region is Iran (*Ibid.*). There is an established shipping route between the two countries, and a strong history of collaboration, more so than other Middle Eastern countries[102] (*Ibid.*). In addition, mechanisms are already in place for technology transfer between the two nations. For example, Iran has also opened up its petrochemical sector in order to attract Indian investment and encourage joint ventures (Verma 2007). However, due to global sanctions, Iran's energy infrastructure is underdeveloped, so much so that, currently it exports its crude oil to India in order get it refined into petroleum products (Verma 2007; Interview B4 2008; Interview B5 2008; Interview B18 2010). These are then imported back from Indian refineries, such as Jamnagar in the state of Gujarat (see Figure 7.5) (*Ibid.*). Furthermore, India has had to come up with creative and circuitous ways to sustain trade and partnership with Iran, particularly in the face of international pressure from countries such as the USA (Verma 2007; Interview B17 2010). In regards to security concerns with shipping, there is only one choke point – the Strait of

[102] Iran, Iraq and Saudi Arabia have the largest hydrocarbon reserves in the region, and these countries have been the traditional exporters of oil to India (Interview B18 2010). Under the rule of Saddam Hussein, India had good relations with (secular) Iraq, which in turn soured relations with (Islamic) Saudi Arabia (Interview B17 2010). Although oil trade has not been necessarily affected, there has been a long-standing tension between Saudi Arabia and (predominantly Hindu) India (*Ibid.*). If oil dependency were not an issue, then the Indian Government would limit trade with Saudi Arabia, primarily due to their financial support for extremist Islamic terrorist groups based in Pakistan (Interview B17 2010; Interview B18 2010). For example, the Mumbai terrorist attack in 2008 was orchestrated by such groups (Interview B17 2010; also see Gall 2014; Fair 2014).

Hormuz[103] – and this is considerably well protected by an array of naval bodies, due to its global strategic importance (Verma 2007; Interview B17 2010; Interview B18 2010).

In comparison, participants from both the security services and the oil industry highlighted an example where an attempt had already been made to collaborate on trans-national energy projects within the region, but failed due to wider geopolitical reasons (Interview B4 2008; Interview B5 2008; Interview C1 2008; Interview C2 2008; Interview C3 2008; Interview B17 2010; Interview B18 2010; Interview C5 2010). The project referred to by all interviewees was the failed proposal of the Iran-Pakistan-India (IPI) gas pipeline, which would have stretched from the South Pars fields in Iran, through Pakistan, to the Barmer region in India (*Ibid.*; also see Verma 2007). The proposed IPI pipeline included significant opportunities for international technology transfer via FDIs and joint ventures for all countries involved (Verma 2007; Interview B4 2008; Interview B5 2008; Interview C3 2008; Interview C5 2010). However, geopolitical factors in the region prevented any such cooperation. This included the high security risk involved with the transit of the pipeline either in close proximity to or through current conflict zones (e.g. Afghanistan and Pakistan, see Fair 2014), combined with the competing interests of USA and China in the region (see Verma 2007; Gall 2014; Fair 2014). Nevertheless, participants from the security services and oil industry pointed out that pipelines are the least secure option, and although it may be more costly, shipping transport of gas (e.g. CH_4 or CO_2) would be the more secure route for any prospective Indo-Iran cooperation (Interview B5 2008; Interview B17 2010; Interview B18 2010; Interview C5 2010) .

When questioned on the feasibility of this scenario in the context of CCS and this case study, interviewees had a general response: regardless of the wider geopolitics in the region, mitigation via CO_2 injection into geological media has to become a *global priority*, before the CO_2 export concept can become a reality for India or any other state (Interview B4 2008; Interview B5 2008; Interview C1 2008; Interview C2 2008;

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[103] The Strait of Hormuz is the primary export thoroughfare for oil, LNG and other petroleum products from Iraq, Iran, Kuwait, Saudi Arabia, Qatar and the UAE, making it one of the most internationally policed region in the world (Verma 2007; Interview B17 2010; Interview B18 2010).

Interview C3 2008; Interview B17 2010; Interview B18 2010; Interview C4 2010; Interview C5 2010). All were of the view that mitigation of CO_2 emissions was not a priority for these countries, and their ambitions for development and industrialisation would take primacy (*Ibid.*). Therefore, interviewees from private industry in particular felt that developed nations would have to take the lead on developing the CO_2 shipping aspect of any prospective CCS project (Interview C1 2008; Interview C2 2008; Interview C3 2008; Interview C4 2010; Interview C5 2010). In addition, representatives from Cairn Energy pointed out that there were largely carbonate reservoirs in the Middle East, therefore more research specific to those geological conditions would be required (Interview C3 2008). This shipping scenario demonstrates the potential impact of macro-level issues, e.g. geopolitics and international security, on the CCS sociotechnical system. Therefore, such issues would need to be considered in order to make the shipping scenario a reality.

7.3.5 Case study Summary and Conclusions

The Cambay Basin area was chosen for a case study on the basis of four selection criteria: (1) its proximity to a good geological storage site; (2) existence of fixed project(s), e.g. new-build power plants or large industrial source of CO_2; (3) it is a politically stable region; (4) there were contacts and linkages with industry in the region that were willing to participate in the study. The region has a history of hydrocarbon exploitation, and depleted fields are presently being considered for gas storage. Also, during the study period, mature oil fields in the Cambay area were being considered for CO_2-EOR. Therefore the interest in CO_2 injection in the region was driven by further extraction of resources, rather than climate change mitigation. Nevertheless, there was interest in CCS because there was also need of a pure CO_2 stream for injection purposes, which could potentially be provided by captured CO_2 from a power plant. However, despite there being a technical opportunity to implement CCS, domestic political disagreements between the Ministry of Power and ONGC in the end prevented any technology transfer taking place. These domestic political issues were also connected to the wider international political stance taken by the Indian Government, discussed in Chapter Six.

Furthermore, the Cambay area is currently being prospected for shale gas, and this could have implications for the integrity of the cap rock in the region. Therefore, neighbouring Mumbai High fields were identified as potentially having more storage capacity than Cambay. However, these are carbonate reservoirs and more research is required on the specific rock chemistry, looking at CO_2-water-rock reaction, if CO_2 is to be retained within the reservoirs permanently. MNCs operating in the region indicated that there were no plans for exploring this option unless the Indian Government showed interest. Given these limitations in storage, the feasibility of exporting CO_2 via ships to suitable storage sites in the Middle East was also explored. This is because, even though the CO_2 shipping aspect of the CCS technological system is still at a very nascent stage, there is an established LNG and LPG trade route between these two regions. Furthermore, there are opportunities for CO_2-EOR at several large mature fields located in countries such as Iran. However, projects such as the failed IPI pipeline demonstrate that unfavourable geopolitical conditions can have a significant impact on technology transfer. Furthermore, currently CO_2 mitigation is not a key priority in the region. Not only stronger international political drivers behind CCS implementation are compulsory, but further research is also required on carbonate reservoirs to assess the technical feasibility.

7.4. Chapter Summary and Conclusions

In addition to the Indian Government's opposition to CCS on the international stage (see Chapter Six), there are key domestic factors that have prevented the uptake of CCS technology during the study period. This chapter highlights a combination of technical and social challenges for CCS implementation, specifically in an Indian context. These include limitations in terms of India's geology, as well as, domestic political issues regarding corruption in key energy sectors and the prevalence of electricity theft (also see Chapter 5). Furthermore, there are security concerns with insurgency in the coal industry, which is essentially the backbone of India's coal sector. A case study on the Cambay basin was used to further illustrate the sociotechnical issues, highlighting specific domestic reasons for the non-transfer of CCS to India.

In regards to India's coals specifically, they are of high-ash content and have a complex chemical composition, which will require conversion (e.g. combustion or gasification) technology to suit these specific conditions. Therefore, technology transfer for CO_2 capture is very unlikely to be in the form of a straight forward turnkey project or developed elsewhere. Indigenous R&D and state support would be required for this aspect of the CCS chain. However, the poor quality of India's coal is not the only aspect that poses a challenge to CCS implementation. India's coal reserves are predominantly located in forested areas and tribal land. There are serious social concerns associated with coal mining in these areas, which started as major development projects set up by the World Bank. The local population has not benefitted from such large coal projects; they are displaced and live in poverty due to a legacy of unsustainable mining practices, which have prevailed since the sector was nationalized in the 1970s. Furthermore, during the study period there was very little environmental regulation, as well as poor governance and extensive political corruption in the sector. This has been extensively profiled in the Indian media and includes senior government officials and the so-called 'mining barons'. Consequently, there is a significant amount of discontent amongst the local population in coal-rich areas and mining practices have directly fomented the Maoist insurgency in the region. Notably, key infrastructures, such as power stations, rail networks and transmission lines, tend to be consistent targets for insurgency attacks. Crucially, CCS technology would perpetuate the use of coal, and given its links with mature energy systems, it has the potential to be at a higher risk for an insurgency attack. For these reasons the Indian coal sector struggles to attract international technology transfer, as MNCs are reluctant to invest in this area.

In the overall context of GHG mitigation in India, efficiency measures in the power sector will take precedent, such as switching to gas-powered plants, over CCS for reasons outlined in Chapter Six. Nevertheless, India is making efforts to bring in efficiency measures to its power sector, and is investing heavily in cleaner and more efficient technology, such as new supercritical and ultra-supercritical boilers. The discussion in Section 7.2.2 illustrates that due to the mixed identity of CCS, India would like to explore some aspects of the technology chain, but not others. For example, India has an interest in IGCC, but this is because hydrogen is produced as a by-product. Essentially, CO_2 capture has another use, not just mitigation. Analysis in Section 7.2.2 also shows that CCS technology transfer may be applicable to other newer technologies, such as the UMPPs.

Building upon the analysis in Section 7.2, the least technically challenging conditions for CO_2 capture were considered to involve plants that rely on imported coal or gas, due to their high efficiency and better quality of fuel. These sources of CO_2 also tend to be on coastal sites, with the potential for shipping links. Based upon these favourable conditions, along with other factors, such as contacts for access to relevant data, the Cambay Basin was selected as the focus for a case study in Section 7.3 to further explore India's reluctance to CCS technology. If only technical factors are considered, Cambay appears to be suitable for CCS because there is relevant infrastructure in place, including supercritical power plants, pipeline networks, LNG/LPG terminals for shipping, and depleted oil and gas fields for potential EOR and CO_2 storage. This area also demonstrates established routes of technology transfer via the private industry, which is operating successfully in all the relevant sectors that could potentially connect a CCS chain. However, it became apparent that key decisions resided with the central Indian Government. Therefore, CCS implementation would not be considered without ambition being shown by the state. The Cambay Basin case study demonstrates the *socio*technical nature of innovation processes.

Furthermore, a significant technical impediment to CCS in this region is the limited amount of storage capacity to match volumes from CO_2 sources. Therefore, a hypothetical scenario of exporting CO_2 to suitable storage sites using ships was explored. In the context of India, the region that would naturally be considered for export is the Middle East, due to its geographical proximity and potential requirement for CO_2-EOR. For political reasons, Iran was thought to be the best choice for potential India CO_2 exports. Though, conversely, also for political reasons, such a trade link would be difficult to establish due to the complex geopolitical factors that surround Iran internationally. Therefore, the broader political dimensions in this region, e.g. international security, restrict India's potential to export its CO_2 emissions in a shipping scenario, given the limited storage capacity in the Cambay Basin.

Chapter 8: Summary, Conclusions and Reflections

8.1 Introduction

The implications of anthropogenic climate change, which is caused and exacerbated by the rise in CO_2 emissions, are very grave for our existence as a global civilization, and steps need to be taken if society is to persist. In particular, the Indian subcontinent is facing a predicament, as it is home to over a billion people with urgent development needs, such as access to food, energy and clean water; yet this population is most vulnerable to the adverse effects of climate change. The paradox is that historically, this part of the developing world has not contributed to the problem of climate change, rather, that onus belongs to the developed world. However, several developing economies are following in the footsteps of the Western industrial revolution and emerging as major CO_2 emitters; India is such an economy, and in light of its predicament, a potential technological solution – Carbon Capture and Storage (CCS) – was chosen as the focus of this thesis.

This study was undertaken in the period 2007-2010, a period of great momentum in developing CCS technologies. Originally, I set out to discover whether CCS technology could be a viable solution for India's heavy use of fossil fuels, notably coal. However, it quickly became clear that the Government of India had serious reservations about CCS technology, or at least, the conceptualisation of CCS that was presented to it by developed countries, notably the UK and EU. Accordingly, this thesis turned to examine in depth the reasons behind India's reluctance to consider CCS as a means for mitigating climate change, focusing on why India was reluctant to implement this technology, despite it being a period during which developing countries with rising emissions, such as India, were under pressure in international negotiations to take climate mitigation action.

The theoretical framework used for this study derives from a mix of social science literatures which focus on and explore the social processes behind technology and its development (see Chapter 2). An interdisciplinary approach has been used, linking STS, technology transfer and IR scholarly work within the empirical chapters (Chapters 4, 5, 6 & 7) in order to examine the case of CCS in India. The literatures discussed in Chapter

Two, when applied together, indicate that technology and politics are inherently connected, and that the success of any technology is fundamentally shaped by the political interests surrounding it. Therefore, the conceptual framing of the thesis has provided for an holistic, sociotechnical analysis of CCS in India.

One of the key insights derived from linking STS concepts with political IR literature in the thesis is that there is a reciprocal relationship between technology and politics. For example, the case of India's nuclear technology programme, discussed in Chapter Five, illustrates how the technology was historically connected to India's independence movement and played a significant role in establishing India's national system of innovation. As a result, nuclear power is still a key part of India's identity, and the expansion of its civil nuclear programme remains a crucial element of India's future development ambitions.

A second insight, emerging from the conceptual framework introduced in Chapter Two is the multiple and mixed sociotechnical identities of CCS. Namely, CCS is not a single technology – but rather a sociotechnical system – and it has multiple potential (policy) objectives (e.g. oil recovery, climate mitigation, hydrogen production). This 'multiple identities' theme is used throughout the empirical chapters (4, 5, 6 and 7), to analyse and explain why India did not implement CCS. The impact of this mixed sociotechnical identity on technology transfer is summarised in more detail under Questions 2 and 2(a) in the following section.

8.2 Synthesis of Main Findings

In this concluding chapter, the synthesis of the main findings of this thesis demonstrate that India's rejection of CCS has been a complex sociotechnical process. The outcomes of this study are discussed according to the research questions presented in Chapter One.

Q. 1: Why did the attempted transfer of CCS technology to India not occur during the period 2007-2010?

Chapter Six demonstrates that India's position against CCS technology can be best understood by India's overall approach to climate change during this study period. At the heart of India's position lies the ethos of Common but Differentiated Responsibilities (CBRD), combined with the logic of co-benefits (see Section 6.2). The latter element implies that development goals are just as important as, if not more so than, climate change objectives. The CBRD approach signifies that developed nations are expected to take the lead on mitigation first, as it is not considered a priority over development for developing countries. Therefore, India was not convinced that CCS made any contribution to India's sustainable development objectives, i.e. there were no so called 'co-benefits', but rather it provided more to the overall mitigation of rising global CO_2 emissions. In other words, CCS provided very little to the people of India, but more to the global commons. It is a case of technological political realism, where the Indian state's prerogative is to protect national interests first.

Furthermore, according to CBRD, the onus for combating climate change should lie with those nations that created the problem in the first place. Consequently, the empirical evidence from my research indicates that India wanted to see CCS implemented elsewhere before considering it as a viable option for the future. Therefore, the need for the demonstration of a fully functioning CCS chain was considered important both politically and technically. In political terms, CCS implementation by developed countries would demonstrate their commitment to climate change mitigation and their alignment to the CBRD approach. The technical reasons are equally important, where participants felt that developed countries should take on the costs and risks associated with implementing a commercially untested technology (see Section 6.2.2). The more specific technical challenges of CCS for India are discussed under Question 1(a).

Q. 1(a): What were the specific technical challenges that ultimately prevented CCS technology transfer to India?

When CCS was analysed specifically in an Indian context (see Chapter Seven) it became apparent that there are distinct India-specific challenges that would make it an unsuitable technology choice. Firstly, India's main priority for power generation during the study period (2007-2010) was energy efficiency, as it operates a very inefficient fleet of power stations, combined with significant losses from an outdated transmission and distribution system. Therefore, any potential carbon capture would only work on new-build power plants, possibly post-combustion capture on supercritical and ultra-supercritical boilers. However, retrofitting such capture would require a large amount of physical space, and India did not factor in any 'capture-ready' plans for any of its new power plants, given its other reservations on CCS.

Secondly, Indian coal has a high-ash content and generally of inconsistent quality, which would require turbines and capture technology that could deal with this type of fuel. The particular characteristics of Indian coal therefore signify that indigenous R&D and innovation would be critical for potential CCS implementation in India. Not only would this require Government support, but it also implies that more inclusive and collaborative forms of technology transfer would be required, i.e. not turnkey projects. Therefore, CCS policy objectives, if effective would have had to be politically aligned at both domestic and international levels. The findings of the Cambay case study (see Section 7.3) indicate that despite there being suitable technological conditions, (e.g. new-build coastal power plants based on imported coal, existing transport infrastructure, proximity to good storage basin), potential CCS implementation in India was ultimately hindered by political dynamics at *both* the domestic and international level, and these were inherently linked.

Notably, the most challenging aspect of the CCS chain for India is storage (see Section 7.2.3 & 7.3). India has limited geological storage capacity in terms of accommodating the volume of CO_2 emissions anticipated over the lifetime of some the newer power plants that are coming online, e.g. the UMPPs. Areas identified as having good storage potential were predominantly based in coastal regions and offshore areas with known depleted oil and gas reservoirs. However, CO_2 storage in these sites could only be considered up to a certain point, and, once they reached capacity, a system would have been required where the excess CO_2 would need to be transported to another suitable storage site. For these reasons, CCS implementation was considered unsuitable during the study period (2007-10).

Q. 2: Can we better understand this lack of adoption by using a sociotechnical system analysis in conjunction with theories of international relations?

IR theories embracing politics provide a useful complement to STS theories, which have been criticised for ignoring the international politics of technology development (e.g. Street 1992; Fritsch 2011; Meadowcroft 2011; Sylvest 2013). On the other hand, STS scholarship provides a more nuanced understanding of the relationship between society and technology, whereas IR/IPE scholars typically take a narrow view on technology, regarding it as an apolitical and passive entity (see Talalay et al. 1997; Herrera 2006; Fritsch 2011; Sylvest 2013). Therefore, an interdisciplinary approach – combining IR and STS – delivers a more comprehensive analysis of why India rejected CCS implementation during the study period. Each discipline has provided different insights, and tools for analysis. The research findings are summarised first through the STS perspective and then through the technology and politics viewpoint. These are then used in combination to summarise and answer the subsidiary questions (2(a) and 2(b)).

Mixed Sociotechnical Identity:

In Chapter Four CCS technology is shown to comprise of three distinct stages: the capture, transport, and permanent geological storage of CO_2 emissions from large point sources, where each stage has different technological configurations. This allows for different combinations of the three stages, giving CCS an inherent flexibility and increased applicability in a variety of contexts, but also a confusing identity. For example, CCS could entail capture from a coal-fired or gas-fired power plant, where the captured CO_2 could be transported either by pipeline or ship, and stored in an offshore depleted hydrocarbon field, or deep unmineable coal-seams. Each set of choices could lead to a very different technological and institutional configuration. This makes CCS intrinsically complicated, giving it a *mixed identity* and, it becomes very challenging to define the boundaries of CCS as a technology. It is for this reason that CCS is viewed here instead as a sociotechnical system, hence embracing its multiple social and technical components, and its complexity.

Moreover, the mixed identity of CCS can also be explained by looking at its origins. In terms of technology innovation, the three stages of CCS actually derive from existing mature technological systems, which can be described as incremental innovations separately designed for a purpose other than CO_2 abatement or climate mitigation. Chapter Four argues, therefore, that CCS is essentially a chain of existing technologies, whereby their integration in order cut CO_2 emissions is the radical or the revolutionary aspect of the whole CCS technological system. Again, this gives CCS a mixed identity, comprising numerous different objectives, and integrating this suite of technologies together as a coherent system for the purpose of climate mitigation poses quite a challenge. Specifically, the challenge in this context is to do with the existing cultures that are already imbedded within the original mature systems. For example, the hydrocarbon industries are inherently based on a philosophy of extraction from geological media, therefore there will be a need to alter this inherited culture so that subsequent technological innovations are not just about taking material out, but also about putting polluting material back in *permanently* (see Section 2.3.2). In addition, each stage of the CCS chain will inherit the culture from an existing system, and these cultures will need to learn to align their goals and work together more effectively (see Section 4.3).

Technological Competitiveness:

The notion that CCS is in fact a political project with a strong business agenda becomes most evident when looking at its role within the UNFCCC negotiations in Section 6.3. For example, the debate about CCS was initially sparked by the need for a CCS methodology for Malaysia and Vietnam, because both countries were interested in gaining funding through the CDM framework for projects that involved hydrocarbon extraction or refinement. However, this caused a divide within developing countries, and India along with several others such as Brazil and small Island nations were quite opposed to its inclusion, arguing that CCS did not contribute to sustainable development, which is what the CDM architecture was originally designed to promote. Notably, those countries in favour, predominantly Middle Eastern countries, were heavily reliant on oil export and trade. Furthermore, the support from Annex 1 countries largely came from those that have a historic technology base in hydrocarbon extraction and exploitation; in this context it was chiefly the UK, Norway, and Australia. Also, there was a strong presence of key industrial players, such as large oil & gas companies, hosting side events as well as being keen observers to the CCS/CDM debate.

Therefore, when viewed through the technology and politics realist lens, where states are rational actors motivated by competitiveness, it becomes evident that the driving forces behind CCS are those with strategic interests. This concept of technological competitiveness, which is linked to IR, is explored further below.

Q. 2(a): How did the UK/developed world framing of the CCS technological system influence the process of attempting to implement CCS in India during the period 2007-10?

As discussed in Chapter One, several plans for demonstration and deployment were announced in countries like the UK, USA, Australia and Canada in 2007. Furthermore, according to the UK and other developed countries, CCS presented a business opportunity by means of technology transfer to developing countries, particularly those heavily locked-into a fossil energy system. Therefore, CCS also appealed to political leaders of certain developed countries at that time, as it would enable their nation to maintain a competitive edge. For example, Tony Blair was very keen to push CCS technology during the 2005 G8 + 5 Gleneagles summit, by including it in the agenda and discussions on energy and climate change. This was bolstered by the development of the UK Government's CAT strategy, developed in the lead up to 2007, drawing upon existing UK expertise in hydrocarbon exploitation, specifically with the aim to present a coherent technological system to newly industrialising countries like China and India (see Section 4.3.1). Therefore, when viewed through technological political realism, it can be argued, that CCS was formulated as a political project with strong business objectives, bolstering technological competitiveness for developed countries.

Yet, despite all the impetus generated for CCS and climate mitigation at the start of the 21st century, a fully integrated CCS chain is yet to be demonstrated anywhere in the world (see Section 4.3). This is largely due to the fact that markets have crashed since then, plus the realisation that a project such as CCS cannot rely on the market. This is because it requires major infrastructures to be put in place, not just in terms of physical structures, but also regulatory frameworks, along with Governments taking up long-term liability for storage sites. Given that CCS remained a radical vision, which hadn't materialised or been implemented during the study period, India understandably had reservations about proceeding (see Section 6.2.2).

India's disinclination to implement CCS can also be linked to issues associated with the mixed identity of CCS, including its multiple policy objectives. As Chapters Four and Seven explain, India was interested in some specific aspects of the CCS chain, but not others. However, CCS advocates from developed countries were trying to present CCS as a coherent technology for a specific purpose, i.e. climate mitigation, and were not sensitive to India's more nuanced understanding of CCS. Consequently, CCS was interpreted by India in a different manner to which it was originally proposed by developed countries. For example, rather than seeing CO_2 as a waste, India viewed it as a resource, and therefore saw CCS more broadly, not solely as a mitigation tool. This is also how countries such as the USA and China are looking into developing the technology, e.g. Carbon Capture Utilisation and Storage, or CCUS rather than CCS (see Section 2.2.2). The term 'utilisation' essentially evolved out of the need for an economic incentive to cover the very high costs associated with such a large-scale endeavour, requiring substantial long-term investment in national infrastructures. Therefore, CO_2 is considered as something of value that can be used, for example, to enhance hydrocarbon recovery, or be used as a feedstock for chemical processes such as fertilizer production.

Q. 2(b): What are the principal social and political factors that prevented CCS from being considered as a viable climate mitigation option in India?

One of the aspects highlighted by the interdisciplinary approach in this study is the reciprocity between technology and politics. A sociotechnical system in particular can have a significant bearing on a state's identity, which is also connected to the concept of technological competiveness (see Section 2.4). With this perspective, the empirical evidence indicates that civil nuclear technology was a competing option with CCS technology during the study period (2007-10). For example, as Chapter Five explains, civil nuclear power is a good comparison with CCS because both contribute to base-load power, both require large capital-intensive infrastructures, and in both cases there is a very significant role of the state, as a customer, regulator and, underwriter. Notably, India's nuclear energy programme is culturally significant; science and technology policies implemented shortly after India's independence in 1947 created national institutions and infrastructures, e.g. IITs, which fostered and exemplified India's capability for highly technical ingenuity and, ability to innovate for large energy systems. India's nuclear energy programme also further demonstrated the importance of politics on technological innovation, particularly in terms of international relations and technology transfer. Indigenous R&D combined with international technology transfer allowed for India to develop its own concept of breeder reactors based on thorium. However, the political ramifications of choosing this particular pathway were not anticipated by India's leaders, and notably, *inter alia* the effects of the Cold War slowed down India's progress in civil nuclear power. Nevertheless, India persevered in this area, and the Indo-US nuclear deal of 2008 allowed for the acquisition of nuclear fuel for civil purposes. Subsequently, the development of thorium reactors regained priority during the study period. Therefore, nuclear power remains a strong ambition, and will have a significant role to play in the future of India's energy system, most likely being the favoured technology choice over CCS in terms of GHG mitigation, and de-carbonising its power sector (see Section 5.3).

India was already showing signs of carbon lock-in at the time of independence. The historical review in Section 5.2 connects India's coal-fired energy infrastructure with the legacy of British colonial rule. Britain's industrial revolution and colonisation are intrinsically linked; coal-fired power plants were first established and run by private British firms in India, prior to independence. Similarly, as discussed under the previous subsidiary question (2(a)), CCS technology has primarily been conceptualised and developed in rich countries (also see Chapter 4). The advocates for CCS were largely from developed countries or, from MNCs associated with those countries (see Section 4.3.1 and Chapter 6). Furthermore, the IP for particular processes within CCS resided with MNCs, e.g. injection technology for EOR, and discussions pertaining to technology transfer of low-carbon technologies to developing countries were a contentious issue within international negotiations (see Section 6.2.2; Ockwell et al. 2010). India felt that that the technology transfer process was imbalanced, as it had been typically in the past, and therefore more in favour of the UK and other developed countries with a strategic interest in developing CCS (see Section 6.2.2). Notably, the empirical evidence shows that, indeed, CCS was a political project with commercial objectives and particularly advantageous to those nations with strong fossil fuel interests (see Section 4.3.1; Meadowcroft & Langhelle 2009; de Coninck & Bäckstrand 2011). India's rejection of the UK/EU conceptualisation of CCS as a discrete technology further demonstrates the fundamental and mutual relationship between technology and international political relations. Particularly, at the macro-level, whereby the Indian state was considered a potential customer.

Moreover, India's lack of enthusiasm for CCS is also connected to security issues surrounding India's coal resource, which is currently an unreliable fuel choice. CCS technology would perpetuate the use of coal. In social and political terms, Section 7.2.1 illustrates the grave externalities associated with the coal sector, which could impede the process of setting up any potential CCS projects. The most serious being the fomented violence and insurgency in resource-rich areas, which is the result of a long legacy of unsustainable mining practices and rapid development, displacing and depriving the local people. Consequently, coal mines, power plants and other associated infrastructure are prime targets for Maoist rebel attacks. Furthermore, governance within the mining sector is mired by corruption, making it an area regarded as inhospitable to MNCs and foreign investment. All of these factors made coal-based CCS an unattractive option for technology transfer, particularly linked to pit-head projects. Again, the security concerns regarding India's coal sector demonstrate the interdependent relationship between politics and technology, this time at the domestic level, which had wider implications for technology transfer and CCS implementation in India during the study period.

8.3 Reflections on the Research Process

<u>Limitations:</u>

A key constraint when working with multiple disciplines is that concepts are often not able to be explored in depth. The result being an overview and appreciation of several different perspectives, rather than the development of a more profound understanding of a single theoretical concept. Therefore, even though interdisciplinary research produces a more holistic and nuanced understanding of a problem, the observations can lack adequate depth. Furthermore, the research methods and tools used for this thesis are exploratory in nature, (e.g. case study research and in-depth interviews), making the findings difficult to replicate. Although, a survey was used to bring balance and triangulate the interview data, there was quite a low response late.

This may be a reflection of the fact that the survey targeted very busy professionals connected to CCS. Notably, at the start of the study period CCS had a high profile internationally, and it was envisioned that this study would have more policy relevance for CCS implementation in emerging economies. However, the 2008 financial crash was not anticipated, and so, by the end of the research period there was very little interest in CCS development from both policy makers and industry due to financial constraints. Therefore, a limitation of the research has been influence of timing, e.g. wider global events can impact the policy relevance of the study.

Lastly, I had underestimated the challenge of managing a multidisciplinary supervisory team, especially because it involved disciplines that have not had much previous collaboration, e.g. law and geology. In addition, the original supervisory team that was put together reflected the policy relevance of CCS at the start of the study period, as well as the high profile of CCS technology within the international arena. Given the diverse backgrounds of the original supervisory team – geology, law and engineering – it was difficult to maintain the interest of supervisors when the study was becoming less relevant to their particular research interests. In my case, due to issues related with access to technical data, the change in research direction gave more prominence to the social sciences and qualitative research methods. Understandably, supervisors with more technical science and engineering backgrounds felt that they could no longer provide sufficient supervision. In hindsight, a social scientist should have had a supervisory role from the start of the study, rather than towards the end.

Strengths:

Despite the limitations discussed above, the interdisciplinary research process has been an eye-opening experience. Given my physical sciences background, I initially approached this research topic with a rather narrow view of technology, i.e. considering it as a passive, discrete entity, and had expectations to conduct quantitative analysis on this topic. However, this research process has essentially broadened my perspective on how technology is developed and applied in real-world contexts. The value of such an interdisciplinary project is that it has built upon my existing technical knowledge and I now have a more mature understanding of the complexities of the relationship between technology and society. Furthermore, this type of research has provided opportunities to explore other disciplines and learn their ‘language’. For example, during the study period, I was able to take LLM classes in international environmental law. Although, a lot of the legal knowledge gained was not directly used in the thesis, it provided useful background training for fieldwork in contexts, such as the international climate negotiations, that I had no prior experience of. Similarly, I had the opportunity to participate in conferences such as the British Association of South Asian Studies (BASAS), giving me the chance to interact with scholars from historical or anthropological traditions. This exposure allowed me to consider the more cultural implications of technology development, particularly the impact of British imperialism on technology development in post-colonial states.

Lastly, the interdisciplinary approach has been most useful in supporting the more creative elements of the research process. Due to the exploratory nature of the research design, I was able to investigate a hypothetical scenario of exporting CO_2 from India to sites with greater storage potential. This particular aspect of the study also provided an opportunity to interact (and in some cases, brainstorm) with non-academic practitioners, e.g. shipping and security professionals, who very rarely deal with academic projects. This is perhaps the beginnings of *trans*disciplinary research, which not only crosses boundaries between scientific and social science disciplines, but additionally involves non-academic practitioners (see Baveye et al. 2014).

8.4 Future Research Directions

Sustainable development in the face of a changing climate is a complex global problem, which needs to be addressed using international structures of governance. This will require fostering good political relationships that enable the technological innovation and transfer required for transitioning to a low-carbon economy. This thesis demonstrates the potential to strengthen STS by extending the analytical approach to integrate additional areas that are familiar in IR research, which considers politics at the macro-level. Often, wider geopolitical and security issues, as well as cultural and historical aspects, e.g. those imbedded within past North-South technology transfers due to colonisation, can get neglected by STS theories (see Herrera 2006; Fritsch 2011; Meadowcroft 2011; Sylvest 2013). Furthermore, STS scholarship largely derives from developed world models, which do not accurately represent how an increasingly interconnected world innovates. In addition, developing countries have different priorities, which influence their receptivity of technological change. IR researchers could also benefit from seeing the additional understanding that can be developed by considering the STS perspective, as within IR scholarship technology is often assumed to be apolitical and exogenous to the international political system. There are political dynamics within the technology development process itself that often get bypassed by IR scholars, who tend to have a more narrow view of technology. Therefore, future research directions could entail the further integration of the concepts and analytical tools from these disciplines to produce an interdisciplinary framework that truly captures the inherent connection between technology and international political relations.

Examples of other specific cases and research avenues that might benefit from such an approach might be, for example, the exploration of CCS in a different country context, such as Brazil or South Africa, which have been more receptive to the idea. Similarly, this framework could be used to analyse the successful transfer of other low-carbon technologies, such as solar or onshore wind in India and other developing country contexts. The interdisciplinary approach used here does not necessarily have to be restricted to large climate mitigation technologies. The integration of STS and IR scholarship could also be useful for exploring the transfer of small-scale adaptation technologies, e.g. taking a more political constructivist perspective, where individuals and small communities have a central role. Furthermore, technology transfer studies have largely occurred in a North-South transfer context with entrenched unilateral processes. Given the growing influence of BRICS economies, perhaps the dynamics of a South-South transfer should also be explored using this interdisciplinary approach. In terms of a wider scope, complex areas where technological innovation is associated with social progress and poverty alleviation, such as global health research, could also find this approach beneficial.

8.5 Concluding Remarks

A social science approach offers useful concepts, ideas and tools for analysing why India rejected CCS in the period 2007-2010. Two particularly relevant bodies of scholarship to this thesis are STS and IR. To date, however, there has been limited work to bring together insights that can be offered by the tools and methodologies that are dominant in these two disciplines. The thesis therefore uses an STS framework, strengthened by insights offered by IR, to offer a more complete analysis of why India rejected CCS during the study period than would have been possible if these two different disciplines had been used in isolation. It does this by, for example, highlighting the intrinsic relationship between technological change and politics. This is particularly relevant for addressing complex societal challenges such as climate change, given that we live in a world characterised by interdependence both technologically and politically.

The findings of this research indicated that CCS implementation in India for mitigation purposes was not in its national interest, but rather, of benefit to the global commons, and specific developed countries with strong fossil fuel interests. India's development and poverty alleviation took precedent, and the Indian state felt that CCS did not contribute to its sustainable development objectives. India's further rejection of CCS was due to CCS being presented as a discrete technology by strategically interested parties, such as the UK/EU, when it is in reality a complex sociotechnical system, with numerous technical configurations and multiple policy objectives. Furthermore, India is technically restricted due to the lack of storage capacity that could match the volumes of potential CO_2 emissions from planned new-build power plants, such as the UMPP projects. Overall, the empirical findings indicate that India's refusal to implement CCS during the study period (2007-10) was a complex political decision, at both international and domestic levels.

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Appendix A – Stakeholder Survey

The following is a blank copy of the survey that was sent to the network of stakeholders, formed over the course of fieldwork trips made in 2008. A summary of the results is presented in Appendix B.

Does Carbon Capture & Storage (CCS) technology have a role in India? A survey of your thoughts and opinions.

Introduction

This survey is intended to gather views about how important climate change, energy and Carbon Capture and Storage (CCS) are perceived to be in India. It has been sent to a wide range of stakeholders with different levels of experience and previous knowledge of energy and CCS in India. Please try to answer as many questions as you can. Since the purpose of this survey is to gather stakeholder views there are no right or wrong answers.

The survey is being carried out by Rudra Kapila (University of Edinburgh) with financial support from Christian Aid. It is part of a short research project to assess the relevance of CCS technology to India (and China) and the potential (or otherwise) for collaboration between the UK (and Europe) and India on this technology being carried out by Rudra and colleagues at the University of Surrey. It is intended that data collected in this survey will also be used in Rudra's PhD research (funded by the UK Energy Research Centre) which is analysing the potential role of CCS in India.

Sections I and II include a total of 14 questions that ask for your views on climate change, energy and CCS in India. Section III consists of 3 questions asking for background information to assist us in data analysis. We expect that the survey will take around 30 minutes to complete. Thank you for your time.

Please send responses to Rudra Kapila at Edinburgh University (r.v.kapila@sms.ed.ac.uk or fax to +44(0) 131 668 3184) by 14th June 2009 or as soon as possible thereafter. If you would like to receive a copy of the reports produced by this project, please provide your e-mail address on the extra sheet circulated with this survey.

Background information about University of Edinburgh, University of Surrey and Christian Aid

University of Edinburgh (Rudra Kapila)

The School of GeoSciences at the University of Edinburgh explores the factors and forces that shape our world and environments in which we live. As a leading interdisciplinary group, it aims to understand the interaction between the Earth's geology, atmosphere, oceans, biosphere and human responses and roles in this complex interplay. Rudra has a first degree in environmental geosciences and was previously based at the Oxford University Centre for the Environment.

Univeristy of Surrey (Hannah Chalmers and Matt Leach)

The Centre for Environmental Strategy at the University of Surrey is an internationally-acclaimed centre of excellence on sustainable development. It takes a multi-disciplinary approach to the analysis of sustainable systems, integrating strong, engineering-based approaches with insights from the social sciences to develop action-oriented, policy-relevant responses to long-term environmental and social issues. Hannah and Matt both have first degrees in mechanical engineering and also have close links with Imperial College London.

Christian Aid

Christian Aid is a Non-Governmental Organisation (NGO) whose primary focus is on development. For more than sixty years Christian Aid has been providing relief to those hit by disaster, helping people help themselves out of poverty and speaking out against injustice. Christian Aid works with partner organisations in a range of countries, including India, regardless of religion or nationality.

Section I: Climate Change and Energy in India

This section contains 9 questions and is intended to explore your opinions on the importance of climate change and energy security for India. It asks for your views on how energy and electricity supply in India might develop between now and 2050. After each question there is space for additional comments. Please feel free to use this as much or as little as you wish.

1. How concerned are you personally about climate change and energy security in India? Please check appropriately.

Answer Choices	**Climate Change**	**Energy Security**
Very concerned		
Moderately concerned		
Neutral		
Not concerned		
Not concerned at all		

Additional comments:
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2. In your opinion, what is the level of priority given to climate change mitigation and energy security by the Indian government? Please check appropriately.

Answer Choices	**Climate Change Mitigation**	**Energy Security**
Very high priority		
High priority		
Medium priority		
Low priority		
Very low priority		
I don't know		

Additional comments:
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3. What proportion of private sector companies in India take climate change mitigation and energy security seriously? Please check appropriately.

Answer Choices	**Climate Change Mitigation**	**Energy Security**
No companies		
A small number of companies		
A moderate number of companies		
The majority of companies		
I don't know		

Additional comments:

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4. In your opinion, which sectors currently contribute the most to India's total carbon dioxide emissions and how might this change? Please <u>identify the three most important sectors and rank them</u> in the order in which you think they contribute to carbon dioxide emissions *(where 1 is 'highest contribution')*.

Sector	**Rank now**	**Rank in 2030**	**Rank in 2050**
Transport			
Agriculture			
Commerce & Industry			
Power (electricity generation)			
Defence			
Other (please specify):			
I don't know			

Additional comments:

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5. In your opinion, what energy resources are most important to meet the energy demand of India and how might this change? Please identify the three most important resources and rank them in the order in which you expect them to contribute to India's energy supply mix *(where 1 is 'most significant contribution')*.

Energy resource	**Rank now**	**Rank in 2030**	**Rank in 2050**
Oil			
Gas			
Coal			
Traditional Biomass			
Other Biomass (e.g. Jatropha for biofuels etc.)			
Hydro			
Renewables (e.g. Wind, Solar)			
Nuclear			
Other (please specify):			
I don't know			

Additional comments:

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6. In your opinion, what energy resources are most important to meet the electricity demand of India and how might this change? Please identify the three most important resources and rank them in the order in which you expect them to contribute to India's electricity supply mix *(where 1 is 'most significant contribution')*.

Energy resource	**Rank now**	**Rank in 2030**	**Rank in 2050**
Oil			
Gas			
Coal			

Traditional Biomass			
Other Biomass (e.g. combustion at power plants)			
Hydro			
Renewables (e.g. Wind, Solar)			
Nuclear			
Other (please specify):			
I don't know			

Additional comments:

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7. In your opinion, what are the main energy security concerns for India now and how might this change in the future? Please identify the three most important concerns and rank them *(where 1 is 'highest level of concern for India')*.

Energy security concern	**Rank now**	**Rank in 2030**	**Rank in 2050**
Lack of diversity in sources of energy supply			
Limited or no access to electricity for large rural population			
Inadequate energy infrastructure			
Highly dependent on imported oil			
Highly dependent on imported gas			
Highly dependent on imported coal			
Highly dependent on traditional biomass			
Other (please specify):			
I don't know			

Additional comments:

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8. If India is planning to invest in a low-carbon and energy secure future, then which technologies should be given investment priority for development by the Indian government and how might this change in the future? Please identify the three most important technologies and rank them *(where 1 is 'likely to be given highest priority')*.

Low Carbon Technology	**Rank now**	**Rank in 2030**	**Rank in 2050**
Wind Energy			
Solar			
Marine Energy (e.g. Tidal, Wave)			
Hydro			
Nuclear			
CCS			
Geothermal			
Microgeneration			
Other (please specify):			
I don't know			

Additional comments:

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9. If India is planning to invest in a low-carbon and energy secure future, then which technologies will be given investment priority for development by private sector industry in India and how might this change in the future? Please identify the three most important technologies and rank them *(where 1 is 'likely to be given highest priority')*.

Low Carbon Technology	**Rank now**	**Rank in 2030**	**Rank in 2050**
Wind Energy			
Solar			
Marine Energy (e.g. Tidal, Wave)			
Hydro			

Nuclear			
CCS			
Geothermal			
Microgeneration			
Other (please specify):			
I don't know			

Additional comments:

Please feel free to make any additional comments on India's energy sector and approach to climate change mitigation here:

Section II: CCS in India

Some of the questions in Section I explored whether CCS may have a role to play in India in your opinion. This section contains 5 questions and considers some more detailed issues around how CCS could be deployed in India, if it is decided that it is a suitable technology to be used in the Indian context. As in Section I, after each question there is space for additional comments. Please feel free to use this as much or as little as you wish.

10. A number of different people and organisations talk and write about carbon capture and storage (CCS), but they don't always have a common understanding of what CCS is. Please could you explain what you think CCS technology includes?

____

11. Please read the following statements and indicate whether you agree, disagree or have no opinion of them.

	Statement	Agree	Disagree	No Opinion
11.1	The existing financial mechanisms (e.g. CDM, Carbon Markets) are insufficient to support and promote clean energy solutions.			
11.2	The international community is not doing enough to create a suitable framework for facilitating technology transfer.			
11.3	The international community is not doing enough to promote technology research & development			

Additional comments:

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One definition of CCS is that it is trapping the carbon dioxide emissions from power stations and industrial sites, then transporting it to be buried deep underground so that it does not escape into the atmosphere. Please use this definition for the remaining questions in this section.

12. Imagine that developed countries have demonstrated the full CCS chain to be safe, secure and functional at a large scale. If India were willing to try out the technology in some initial projects and then decides that wider deployment would be appropriate, then who should be responsible for covering costs and providing training? Please identify and rank the three most important groups for each aspect (A, B, C & D) that should make a contribution in your opinion (*where 1 is 'most significant contribution'*).

	A. Training for initial projects	**B. Finance for initial projects**	**C. Training for wider deployment**	**D. Finance for wider deployment**
Developed country Governments				
Developed country private sector				
Developed country public				
Indian Government				
Indian private sector				
Indian public				
Other (please specify):				

Additional comments:

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13. In your opinion, what are the most important actions that should be taken by developed countries (such as the UK, USA etc.) to support the development and deployment of low-carbon technology in India, including CCS if it if it is decided that it is a suitable technology to be used in the Indian context?

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14. In your opinion, what are the most significant challenges to implementing CCS technology in India? Please identify and rank the three challenges that you think are most important *(where 1 is 'most likely to prevent CCS implementation in India')*.

Barriers to CCS	**Rank for initial projects**	**Rank for widespread deployment**
Technology readiness		
Construction costs		
Running costs		
Availability of skilled people		
Safety of carbon dioxide capture process		
Safety of carbon dioxide transport		
Safety of geological storage of carbon dioxide		
Public acceptability		
Political acceptability		
Financing mechanisms (e.g. loans, CDM etc.)		
Water supply		
Inadequate geological storage capacity		
High ash content in Indian coal		
Other (please specify):		
I don't know		

Additional comments:
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Please feel free to make any additional comments about CCS in India here:

Section III: Background information

This section contains 3 questions in total and is intended to collect information to help us analyse any significant differences between the perspectives of different stakeholder groups who have participated in this survey.

15. Do you work in the energy field directly? (Please delete appropriately)

Yes

No (if no, then please skip question 16)

16. What is the main focus area of your work? (check all that apply)

Oil & gas industry ☐

Coal industry ☐

Power industry ☐

Transmission/distribution ☐

Renewable energy ☐

Energy Policy ☐

Energy financing ☐

Regulation ☐

Other (please specify) ____________________________

17. What is your profession?

Policymaker ☐

Regulator ☐

Technical expert ☐

Business planner ☐

Policy analyst ☐

Lobbyist/campaigner ☐

Researcher ☐

Other (please specify) ____________________________

Thank you for your time in filling out this survey, your opinions and comments are very much valued and appreciated.

Data collected in this survey will be presented in a research report written by Rudra and colleagues at the University of Surrey for the Christian Aid project. It will also be used in Rudra's PhD thesis and related academic papers. The use of data will follow standard academic practice, so your identity (including company/affiliation) will not be reported although your profession and sector may be, where appropriate. No other use of the information gathered will occur without your prior written consent.

Appendix B – Survey Results Summary

Below is a summary of the results of the survey in Appendix A. The survey was carried out in May - June 2009 and, it was designed to explore stakeholder views on the prospects of CCS technology in India. This Appendix shows original data that has also been published in Kapila et al. (2009). The data was collected and analysed solely by Kapila. The more detailed version of these results can also be found on pages 23-36 of the original report (available at: http://www.sccs.org.uk/expertise/reports.html#sccsworkingpapers).

Section I – General Attitudes to Climate Change and Energy in India

The results in this section refer to the following questions, with the choices for answers in brackets:

Q1 – How concerned are you personally about climate change and energy security in India? *(I am very concerned/moderately concerned/neutral/not concerned/not concerned at all)*

Thirteen out of the 18 respondents were 'very concerned' about climate change, and fourteen out of the 18 were 'very concerned' about energy security. Some respondents commented that these two challenges needed to be addressed collectively because of India's increasing energy demand for development and that the impacts of climate change would largely affect the poor. A few were moderately concerned about climate change in comparison to energy security, commenting that "energy security is extremely essential for sustained economic growth and poverty alleviation," and that climate change was an issue that would gain equal importance at a later stage in India. One respondent was of the opinion that "the energy policy and development of India will have a significant impact on global climate."

Q2 – In your opinion, what is the level of priority given to climate change mitigation and energy security by the Indian Government? *(The Indian Government gives climate change mitigation and energy security very high priority/high priority/medium priority/low priority/very low priority/I don't know)*

The majority of respondents thought that climate change mitigation was given a 'medium' to 'high' level of priority. In comparison, the majority thought that energy security was given a 'high' to 'very high' level of priority by the Indian Government. One comment was, "energy security has been on the top of the agenda for quite some time now, whereas climate change mitigation has started to pick up recently."

Q3 – What proportion of private sector companies in India takes climate change mitigation and energy security seriously? *(No companies/a small number of companies/a moderate number of companies/the majority of companies/I don't know if any companies take climate change mitigation and energy security seriously)*

The greater part of responses considered that a 'small' to 'moderate' number of companies took climate change mitigation and energy security seriously. Respondents commented that the motivation to undertake any mitigation measure was primarily business driven for survival and growth, and therefore likely to be less of a concern at present to the private sector. It was noted, however, that the Clean Development Mechanism (CDM) had been "quite instrumental in spreading more information about climate change mitigation in India." Nevertheless, one stakeholder commented that from what they had observed in the Indian business and academic communities, climate change was generally regarded as the "environmental fad of the decade, instead of a serious problem." They thought that there was still "an acute lack of awareness" outside a very small group of people in Delhi and other metropolises in India. It was commented further that "individual companies view energy security from their own short-term perspective rather than the wider context of [the] long-term future of generations to come."

Q4 – In your opinion, which sectors currently contribute the most to India's total carbon dioxide emissions and how might this change? Please identify the three most important sectors and rank them in the order in which you think they contribute to carbon dioxide emissions (where 1 is 'highest contribution'). *(Transport, Agriculture, Commerce & Industry, Power (electricity generation), Defence, Other, I don't know)*

Rank	Now	2030	2050
1	Power	Power	Transport
2	Transport	Commerce & Industry	Commerce & Industry, Power
3	Commerce & Industry	Transport	Agriculture

The sectors respondents identified as the current most significant contributors to climate change were 'power,' 'transport,' and 'commerce & industry,' where a clear majority (16/18) ranked the power sector at the top, transport second and the commerce and industry sector at third. By 2030, most respondents still ranked the power sector as the top contributor, but commerce and industry moved to second and transport was ranked at third. It was noted that India was "in need of infrastructure and that this was going to be the development objective for the next couple of decades." In addition, it was thought that after thermal power plants, the steel sector in particular was most carbon intense.

The greater part of the responses expected the transport sector to eventually become the top contributor to India's carbon emissions by 2050, and that power, commerce and industry would be jointly ranked as second. By 2050, the majority thought that the agriculture sector would have the third highest contribution to India's overall carbon emissions. These non-CO2 contributors to the greenhouse gas emissions are typically difficult to reduce below a certain level, partly since they are associated with food production and are difficult to avoid.

Q5 – In your opinion, what energy resources are most important to meet the <u>energy</u> demand of India and how might this change? Please identify the three most important resources and rank them in the order in which you expect them to contribute to India's energy supply mix (where 1 is 'most significant contribution').
(Oil, Gas, Coal, Traditional Biomass, Other Biomass, Hydro, Renewables, Nuclear, Other, I don't know)

Rank	Now	2030	2050
1	Coal	Coal	Coal
2	Oil	Oil & Gas	Oil & Gas
3	Gas	Hydro & Renewables	Renewables

Coal was ranked outright as the main energy resource to meet India's energy demand at present, and it is expected to remain the primary choice of fuel to meet energy demand through to 2050. The majority also considered oil and gas to be an important part of the current energy resource mix, ranking them second and third, respectively. By 2030, oil and gas were jointly ranked at second, and hydropower and renewables collectively formed the 3rd most important resource expected to be used to meet energy demand. By 2050, it was expected that renewables such as wind and solar would become more prominent than hydro and form the third most important energy resource for India. Though most stakeholders saw a shift in favour of renewable sources of energy, it was noted that this would hinge upon whether the cost of renewables-based electricity could be "drastically brought down through technology break-throughs, international cooperation, and high volume production of renewable based generation technologies." Another comment made in terms of energy resources was that "water availability for irrigation would become a barrier for the development of the bio-fuel industry", and that land acquisition for the renewable sector could become an issue in the future.

Q6 – In your opinion, what energy resources are most important to meet the electricity demand of India and how might this change? Please identify the three most important resources and rank them in the order in which you expect them to contribute to India's electricity supply mix (where 1 is 'most significant contribution'). *(Oil, Gas, Coal, Traditional Biomass, Other Biomass, Hydro, Renewables, Nuclear, Other, I don't know)*

Rank	Now	2030	2050
1	Coal	Coal	Coal
2	Hydro	Hydro	Nuclear
3	Nuclear	Nuclear	Hydro & Renewables

Coal was again ranked as the most important resource through to 2050 for meeting India's electricity demand. Hydropower was ranked as the second most important resource for electricity at present and through to 2030. By 2050, it is expected to drop to third position as part of a renewables mix that includes solar and wind. Responses consistently featured nuclear in the electricity mix, where the majority see it as the third most important resource at present and through to 2030. By 2050 nuclear is envisioned to become second to coal in terms of electricity generation. It was noted that certain technologies such as hydro and nuclear had yet to be developed for their full potential, but until then, "coal is king."

Q7 – In your opinion, what are the main energy security concerns for India now and how might this change in the future? Please identify the three most important concerns and rank them (where 1 is 'highest level of concern for India'). *(Lack of diversity in sources of energy supply, Limited or no access to electricity for large rural population, Inadequate energy infrastructure, Highly dependent on imported oil, Highly dependent on imported gas, Highly dependent on imported coal, Highly dependent on traditional biomass, Other, I don't know)*

Rank	Now	2030	2050
1	Limited/no access for rural population	Dependence on imported oil, gas & coal	Dependence on imported oil, gas & coal
2	Dependence on imported oil	Inadequate energy infrastructure	Inadequate energy infrastructure

3	Inadequate energy infrastructure	Limited/no access for rural population	Limited/no access for rural population

When asked to consider India's main energy security concerns, the greater part of respondents thought that the 'limited or no access to electricity for the large rural population' was of primary concern at present, with 'dependence on imported oil' and 'inadequate energy infrastructure' as second and third, respectively. By 2030 and through to 2050, respondents expected that dependence on imported oil and other fossil fuels such as coal and gas will become the main concern, with inadequate energy infrastructure ranked second. During this period it is envisioned that the lack of power to the rural poor will still be an issue, with respondents ranking it as the third most important energy security concern.

Q8 – If India is planning to invest in a low-carbon and energy secure future, then which technologies should be given investment priority for development by the Indian Government and how might this change in the future? Please identify the three most important technologies and rank them (where 1 is 'likely to be given highest priority'). *(Wind Energy, Solar, Marine Energy, Hydro, Nuclear, CCS, Geothermal, Microgeneration, Other, I don't know)*

Rank	Now	2030	2050
1	Nuclear & Hydro	Solar	Solar & Nuclear
2	Wind	Nuclear	Hydro
3	Solar	CCS & Hydro	CCS

For the current Indian Government, nuclear and hydro were equally considered as the current top investment priority for India, with wind and solar as second and third, respectively. By 2030, the majority ranked outright solar as the main investment priority, with nuclear second, and CCS and hydro equally at third. By 2050, stakeholders ranked nuclear and solar equally as the top investment priority for the Indian Government, with hydro ranked second and CCS third. One respondent was of the opinion that "alternate renewable technologies are still in a nascent development stage, and the scene will change if R&D models improve or transfer of technology is undertaken." It was also noted that "CCS will remain at the end of the technology spectrum, as it reduces the energy efficiency of the plant, in an already energy deficit country."

Q9 – If India is planning to invest in a low-carbon and energy secure future, then which technologies will be given investment priority for development by private sector industry in India and how might this change in the future? Please identify the three most important technologies and rank them (where 1 is 'likely to be given highest priority'). *(Wind Energy, Solar, Marine Energy, Hydro, Nuclear, CCS, Geothermal, Microgeneration, Other, I don't know)*

Rank	Now	2030	2050
1	Solar & Wind	Solar & CCS	CCS
2	Hydro	Wind & Hydro	Solar
3	Microgen	Microgen	Nuclear

Stakeholders considered solar and wind to be equally most important, hydro as second and microgen as third for current investment by private sector industry in India. By 2030, CCS was thought to be as important as solar in terms of investment priority. Wind and hydro were ranked second and microgen as third. By 2050, CCS was ranked outright as the top investment priority for private industry, with solar and nuclear as second and third, respectively. It is important to note here that roughly half the respondents answered 'don't know' for the 2050 option, a few commenting that it was too difficult to gauge at this point what direction the private industry would take in the future.

Section II – CCS in India

This section of the survey asked five questions in total, specifically on CCS technology and whether it may have a role to play in India. The questions also consider more detailed issues around how CCS could be deployed in India, if it is decided that it is a suitable technology to be used in the Indian context. Results are given after each question with choices for answers in brackets, where relevant.

Q10 – A number of different people and organisations talk and write about carbon capture and storage (CCS), but they don't always have a common understanding of what CCS is. Please could you explain what you think CCS technology includes?

All responses seemed to indicate that the respondents were quite familiar with the CCS paradigm, with answers including:

- "Technologies to de-carbonise fossil fuel combustion/gasification. A process by which CO_2 from the combustion of fossil fuels is prevented from being released into the atmosphere by being "captured". The CO_2 is then pipeline transported, and stored/sequestered, using geological storage/conversion processes."

- "It includes capture of carbon dioxide from the flue gases generated due to combustion of carbonaceous fuel, and capture of CO_2 generated during production syngas or producer gas or water gas. The captured CO_2 is separated from capturing media to obtain pure CO_2. The pure CO_2 is transported in supercritical state to the identified geological site for storage."
- "As per my understanding CCS should include separation of CO_2 from source emissions in purest possible concentration using adsorptive or membrane separations and subsequently to be sequestered for permanent storage. Alternatively, if close loop is to be followed then CO_2 should be used for its valorisation to produce hydrocarbon fuels."
- "As the name suggests, CCS includes capture, storage and transportation of captured CO_2 to sinks – geological seams, oceans. Capturing is most capital intensive in a CCS project followed by transportation via pipeline or ships. While post-combustion technology in a power and O&G[104] sector is more common – a mature technology market, it is economically feasible in cluster of industries to reduce the costs. Pre-combustion technology is more common in emerging technology market, while oxyfuel is in early development phase."

Q11 – Please read the following statements and indicate whether you agree, disagree, or have no opinion of them:

Q11.1. "The existing financial mechanisms (e.g. CDM, Carbon Markets etc.) are insufficient to support and promote clean energy solutions." *(I agree/disagree/have no opinion)*

The majority of stakeholders (13/18) agreed with the statement above, three respondents disagreed, and two had no opinion. In the context of the CDM and carbon markets, it was commented that "there is very little support and incentives for CDM for SME's [small and medium enterprises] in developing countries such as India." One respondent commented further: "I agree with the view of some of the technocrats in India that CDM and carbon markets of the future will not give enough support to CCS, for which investment is much higher than other low carbon technologies." Another respondent concurred: "In my opinion, policy changes that allow CCS to be part of the CDM will be insufficient due to the energy penalty of the technology."

[104] Oil & Gas sector.

Q11.2. "The international community is not doing enough to create a suitable framework for facilitating technology transfer." *(I agree/disagree/have no opinion)*

The greater part of respondents (14/18) agreed with the statement above, one person disagreed, and the remaining three had no opinion. The overall process of technology transfer was met with some scepticism; it was considered to "just mean being directed to a private company, which in turn charges large amounts as fees to share the knowledge of the technology." Several additional comments were made regarding the issue of technology transfer including:

- "The Doha declaration on Environmental Goods and Services needs to be brought in line with carbon capture technologies to reduce the trade barriers, so that transfer of technology can penetrate at a faster pace."
- "There has been very limited financing and technology transfer from developed to developing countries. Also the technologies being given are not necessarily those which developing countries are currently comfortable with at the moment."
- "Technology transfer is a difficult issue due to the corporate structure of many energy companies and equipment suppliers, especially when met by large nationalised companies."

Q11.3. "The international community is not doing enough to promote technology research & development." *(I agree/disagree/have no opinion)*

There was a more varied response to this statement, with half of the respondents in agreement, six out of the eighteen disagreeing, and the remaining three having no opinion. It was noted that "R&D is universal, so that seems to be going ok, it's the transfer part that is the issue, as is nationally appropriate energy research." One stakeholder was of the opinion that activities are in place, but more effort is needed to involve India more in fundamental research and technology development. It was commented further that the "development of solutions required have to be more specific/designed for India – the technology needs to be appropriate."

Q12 – Imagine that developed countries have demonstrated the full CCS chain to be safe, secure and functional at a large scale. If India were willing to try out the technology in some initial projects and then decides that wider deployment would be appropriate, then who should be responsible for covering costs and providing training for the following aspects? Aspects: (a) training for initial projects; (b) financing for initial projects; (c) training for wider deployment; (d) finance for wider deployment. *(The three most important groups that should make a contribution are developed country governments/developed country private sector/developed country public/Indian Government/Indian private sector/Indian public/other)*

Rank	Training for initial projects	Finance for initial projects	Training for deployment	Finance for deployment
1	Developed country governments	Developed country governments	Developed country private industry	Developed country governments
2	Developed country private industry	Developed country private industry	Developed country governments	Indian Government & private sector
3	Indian Government	Indian private sector	Indian Government	Developed country private industry

(a) *Training for initial projects*: the greater part of the respondents (17/18) thought that the developed country governments should pay for the training for initial projects. The developed country private sector and the Indian Government were ranked second and third, respectively.
(b) *Financing for initial projects*: the majority (17/18) of respondents thought that governments of developed countries should also provide financing for initial projects. The developed country private sector and the Indian private sector were considered as the second and third most important groups that should make a contribution.
(c) *Training for wider deployment*: it was thought by most (15/18) that responsibility for covering costs for training for wider deployment should be carried out by the private sector industry from developed countries foremost. In addition, governments from developed countries and India were thought to be equally important after the private sector, in terms of training.
(d) *Financing for wider deployment*: developed country governments were ranked first in regards to covering the costs for wider deployment. The Indian private sector industries along with the Indian Government were thought to be equally the second most important group responsible for financing projects. The private sector from developed nations was ranked third.

One stakeholder commented that this question was "rather tricky, just because the differentiation between governments, public and private sector is hazy and taxation can unite those three. In addition, it should be noted that several respondents thought that there should have been another separate option as 'International Finance Institutions' such as the World Bank, International Monetary Fund, and the Asian Development Bank. It seems likely that if this category had been available then it would have appeared in the ranking of organisations that have a role in financing CCS projects.

Q13 – In your opinion, what are the most important actions that should be taken by developed countries (such as the UK, USA etc.) to support the development and deployment of low-carbon technology in India, including CCS if it is decided that it is a suitable technology to be used in the Indian context?

This was an open-ended question, which gathered a variety of responses. Suggestions were made to support development by "facilitating vendor to vendor transfer of technology for components and/or CCS," and creating India as a low-cost manufacturing hub, "as India does not have sufficient geological seams for storage, power plants are scattered and pipeline transfer could be costly." Further comments made in regards to CCS development were that the focus should be on "global R&D", whereby facilitating frameworks for setting up a carbon price, technical and institutional capacity building, assuring technology transfer and financial aid are all very important factors.

One stakeholder was of the opinion that CCS demonstration plants should be built and operated as soon as possible in developed countries, followed by funding for a demonstration plant in India. This would require the development of international industrial and academic research collaboration to develop and deploy low carbon technologies. They added that "it is critical that whatever technologies are developed and deployed, they must be appropriate for India (in terms of geography, society, development)" and that in order to achieve this "full engagement and collaboration is required" whereby "India gets (part) ownership of the technologies."

Q14 – In your opinion, what are the most significant challenges to implementing CCS technology in India? Please identify and rank the three challenges that you think are most important in the context of initial projects and for widespread deployment. *(The top three challenges to implementing CCS are technology readiness/construction costs/running costs/availability of skilled people/safety of carbon dioxide capture process/safety of carbon dioxide transport/safety of geological storage of carbon dioxide/public acceptability/politically acceptability/financing mechanisms (e.g. loans, CDM etc.)/water supply/inadequate geological storage capacity/high-ash content in Indian coal/other/I don't know)*

Rank	Initial projects	Widespread deployment
1	Technology readiness	Technology readiness
2	Construction & running costs	Inadequate geological storage capacity

3	Political acceptability	Construction & running costs
4	Financing mechanisms	Political acceptability
5	Safety of geological storage	Safety of geological storage

Most respondents ranked at least five to eight challenges in response to this question, although only three were asked for, and the 'top five challenges' are, therefore, reported here based on the rankings given by the respondents. It is also important to note that some of the respondents thought that these options were not mutually exclusive. For example, as technology develops changes in costs can be expected. This indicates that any actions taken to address challenges to CCS must consider a relatively complex web of interrelated issues if they are to successfully support demonstration and/or deployment.

General comments made on implementing CCS projects gave the impression that the concept of CCS is far from established as an option for deployment in India - bringing it forward first at the government policy level, then at the public level, or possibly both together. 'Technology readiness' was regarded as the main challenge in terms of initial projects and widespread deployment, where the general feeling was that CCS had to be technologically demonstrated in developed countries before it could be applied to India. In terms of 'technology readiness' in particular, it was generally thought that trying out CCS with low efficiency plants would reduce their overall efficiency even further. One stakeholder was of the opinion that "due to the age of the plants in India, their efficiency is about 35% and therefore not suitable for CCS, as 40% is recommended as a good figure for installing capture capability."

A few stakeholders thought it would be particularly interesting to see how CCS would cope with the high ash content of Indian coal, or whether it required to be based on imported coal. It was emphasized that "due to the characteristics of Indian coal, the technologies being developed in the West, such as IGCC, might not be a viable option for India [due to the loss of efficiency by using high-ash coal], but post-combustion capture might be a good option." There was the general view that if India were to come closer to adopting the technology, then research specific to Indian coal conditions was needed.

Furthermore, stakeholders viewed the technology in its current state to be too expensive, not only in construction but also in terms of running costs. Possible repercussions highlighted included "additional fossil fuel emissions, auxiliary power consumption, deterioration in efficiency of the generation and the cost involved in supplementing the generation due to the loss of efficiency." In addition, a comment was made on the concept of 'capture-readiness': "Building a power plant that is 'capture-ready' makes it less efficient by 1.5-2% because of turbine design, which has to allow for the secondary stream of steam for the capture facility. Cumulatively, these losses could be substantial since the losses will have to be borne until the capture facility is in place (which could take ten years or more), and there is no certainty that the plant will be fitted with the capture facility in the future."

Finally, it is interesting to note that stakeholders from different sectors within industry had varying viewpoints on the potential for implementing CCS technology. For example, it was commented: "Private power generators such as Reliance have little incentive to be involved in CCS since they have no influence over pricing of electricity. The central and state governments decide the tariff structure for electricity. This implies that the private players have no way of increasing the tariff, especially if they implement CCS and pass on the cost to the consumer." In contrast, it was noted that the petroleum industry is more likely to have an interest in CCS due to the incentive of EOR, citing examples such as ONGC's Ankaleshwar/Hazira project and the MoU signed with StatoilHydro in 2008[105]. However, since then the StatoilHydro deal has reached a stalemate due to disagreements on the way the project was heading[106].

[105] See: http://www.statoilhydro.com/en/NewsAndMedia/News/2008/Pages/CooperationIndia.aspx

[106] See: http://www.rediff.com/money/2008/aug/26ongc.htm

Appendix C – Overview of Survey Participants

Below is a table of the organisations that participated in the survey presented in Appendix A. This information was collated from the responses to questions 15-17 in Section III of the survey. It should be noted that even though there were 18 respondents out of the 65 invited to take part, only 13 organisations are listed below. This is because in some cases, more than one survey was sent to an individual organisation, so that a range of professionals that are typically present in a single institution due to the multidisciplinary nature of the subject, were included in the sample. For example, surveys were returned by a business planner and a technical expert, both based at Reliance Industries Ltd.

Sector	Organisation	Profession/area of work	Respondent no.
Industry	Infrastructure Development Finance Company Ltd.	Technical expert	5
	KBR	Technical expert & business planner; oil & gas industry, energy policy, power	3 & 4
	Schlumberger	Technical expert & business planner; energy financing	1 & 2
	Reliance Industries Ltd.	Technical expert & business planner; energy financing	8 & 9
Indian Government	Ministry of Environment and Forests	Senior advisor/policy analyst	16
Research	The Energy Resources Institute (TERI)	Researcher & policy analyst; renewables, energy policy	12 & 13
	Omar-Al-Mukthar University, Libya	Academic; energy education & research	15
	Integrated Research and Action for Development (IRADe)	Researcher & policy analyst; renewables, energy policy	10 & 11
	Heriot Watt University	Academic; energy education & research	6
	University of Nottingham	Academic; energy education & research	7
	Indian Institute of Technology, Mumbai	Researcher; renewables, energy, climate change	14
	National Environmental Engineering Research Institute (NEERI), Nagpur	Researcher; renewables, power	18
	World Institute of Sustainable Energy (Wise)	Researcher/policy analyst; renewables, energy policy	17

Appendix D – Technical Interview Questions

The following is an interview guide that was sent to Cairn Energy containing a set of technical questions. This was sent to the Cairn Energy team in advance so that they had an idea of the type of information that was to be discussed, but also it was like a 'wish list' of the kind of data required. Incidentally, not all of the information requested was provided because some of the data was considered to be commercially sensitive. Also, permission could not be obtained by the Indian Government to use or publish the data, even if discussed informally.

Location & Maps:

- Location/map of main production field(s) in basin
- Possible to get map of top of reservoir?
- What is the projection and sphaeroid of the map? (needed for GIS)
- Are there any natural sources of CO_2? Locations will help to add to the map
- How close is the field to the refinery?

Reservoir Attributes:

- What were the oil and gas reserves in place estimated to be? I.e. STOIIP & GIIP
- What is the production per month?
- How long will production last? I.e. Cessation of Production date
- If production has stopped, what percentage has been recovered?
- How deep is the reservoir?
- Possible to get a composite well log?
- What is the porosity?
- What is the permeability? (e.g. horizontal/vertical)
- What is the current reservoir pressure?
- What was the reservoir pressure originally?
- What is the API gravity?
- Are there any saline aquifers nearby? Is there aquifer support during production? (E.g. high, med, low?)
- What is the sand thickness and layering of reservoirs?
- Has the reservoir been water-flooded?

Thoughts on Enhanced Oil Recovery (EOR):

- What do they perceive are the main barriers to EOR? E.g. costs? Legal? Practicalities?

- If they were considering EOR, what would they need to know? What kind of info do they need?

- What would be required to make it happen? E.g. pipe network? Logistics? What are the practicalities? The reality?

- What are ONGCs plans in the area? Does this affect their plans?

- Under what circumstances would they build pipelines?

- What are the rival technologies for EOR? (e.g. new wells & cost; polymer injection; water injection)

Confidentiality:

I am not looking for commercially sensitive data but rather general or even old information that I could use to build a case study around the Cambay basin. If required to, we are willing to sign a confidentiality MoU. This is a standard procedure that our institute goes through because it is quite common to have collaborations between industry and the University of Edinburgh. We intend to publish the general conclusion, but would ensure that any data will not be attributable to specific sites or companies if required to do so.